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PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by M. R. Banks and S. J. Smith

and Published by the Society

Hobart

Tasmania

20 DECEMBER 1991

VOLUME 125

MUSEUM OF VICTORIA
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PLEASE NOTE

There was no volume 124, **part 2** published.

Volume 124 is complete with issue no. 1.

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VOLUME 125

COUNCIL AND OFFICE BEARERS

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President
His Excellency the Governor of Tasmania
General Sir Phillip Bennett, AC, KBE, DSO

Vice-Presidents

Dr J.S. Rogers
Mr G. Davis

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Mrs G. Lord
Dr P.G. Quilty
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Honorary Editor
Dr M.R. Banks, AM

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 125

Contents

	page
Annual report	iv
HANNAN, D.G. & COLHOUN, E.A. — When were the Walls of Jerusalem last glaciated?	1
RUHBERG, H., MESIBOV, R., BRISCOE, D.A. & TAIT , N.N.— *Tasmanipatus barretti* gen. nov., sp. nov. and *T. anophthalmus* sp. nov.: two new and unusual onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania	7
MESIBOV, R. & RUHBERG, H. — Ecology and conservation of *Tasmanipatus barretti* and *T. anophthalmus*, parapatric onychophorans (Onychophora:Peripatopsidae) from northeastern Tasmania.	11
SHAPCOTT, A. — Dispersal and establishment of Huon pine (*Lagarostrobos franklinii*)	17
TAYLOR, R.J. — Distribution and habitat of *Helicarion rubicundus* (Pulmonata: Helicarionidae), a rare land snail.	27
HORWITZ, P. & KNOTT, B. — The faunal assemblage in freshwater crayfish burrows in sedgeland and forest at Lightning Plains, western Tasmania	29
PEMBERTON, D., BROTHERS, N. & COPSON, G. — Predators on marine fish farms in Tasmania	33
EDGAR, G.J. — Seasonal distribution patterns of fishes within the Bathurst Harbour estuary, southwestern Tasmania	37
PLOMLEY, B. & BARBER, L. — The form of the hair follicle in the human scalp as an indicator of human relationships	45
ANDREWS, A.P. — Observations on the Tasmanian mudfish, *Galaxias cleaveri* (Pisces: Galaxiidae)	55
EDGAR, G.J. & CRESSWELL, G.R. — Seasonal changes in hydrology and the distribution of plankton in the Bathurst Harbour estuary, southwestern Tasmania, 1988–89	61
VAN DE GEER, G., FITZSIMONS, S.J. & COLHOUN, E.A. — Holocene vegetation history from King River Railway Bridge, western Tasmania	73
ERRATA:	
TIDWELL, W.D., KIM, J. & KIMURA, T. — Mid-Mesozoic leaves from near Ida Bay, southern Tasmania, Australia	79
TIDWELL, W.D., NISHIDA, H. & WEBSTER, N. — *Oguracaulis banksii* gen. et sp. nov., a mid-Mesozoic tree-fern stem from Tasmania, Australia	79

Design of front cover and spine by Mr Chris Cowles, Tasmanian School of Art, University of Tasmania.

ROYAL SOCIETY OF TASMANIA
Annual Report for the Year 1990

The Council has the honour to present to members the following report on the activities of the Society during the year.

Council and Office Bearers

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Honorary Auditor
Mr R.J. Dwyer

Honorary Editor
Dr M.R. Banks, AM

Assistant Honorary Editor
Dr S.J. Smith

President

His Excellency General Sir Phillip Bennett took the chair as President of the Society, at the Annual General Meeting and at the Annual General Meeting of the Northern Branch.

Deaths

The deaths of the following members are recorded with regret:

Mr J.D. Abey
Mr T.E. Brain
Mr L.W. Chipman
Mr G.P. Duffy
Mr W. Schaap
Mr E.G. Terry

The death of Dr Lloyd Robson, who was awarded the Clive Lord Memorial Medal in 1989, is also recorded with regret.

Annual Meeting

At the Annual Meeting on 6 March, Professor O.M. Roe retired as Vice-President and Mr G. Davis and Mr M.J. Walshe as Members of the Council. The following were elected:

Vice-President	Mr G. Davis
Members of Council	Mr R. Kerrison, Mrs G. Lord
Honorary Secretary	Mr D.R. Gregg
Honorary Treasurer	Mr T.A.H. Knight
Honorary Auditor	Mr R.J. Dwyer

Membership

The membership is 453, a decrease of 28, and is made up as follows:

	Northern Branch	Total
Honorary Life Members	2	7
Life members	12	37
Ordinary Members receiving *Papers and Proceedings*	68	290
Ordinary Members not receiving *Papers and Proceedings*	47	98
Associate Members	13	21
	142	453

Council Meetings

The Council met four times during the year.

Amendments to Rules

At the Special General Meeting held on 4 September, a new Rule 41 was added reading:

> No further Life Members shall be admitted to the Society as from 4th September 1990.

In addition new rules for awards of medals were adopted.

Increase in Subscriptions

At the Special General Meeting on 4 September, it was resolved, on the recommendation of Council, that from the beginning of 1991, annual subscription be as follows:

Members receiving the *Papers and Proceedings*	$30.00
Members not receiving the *Papers and Proceedings*	$18.00
Associate Members	$12.00

Proposed Art Gallery of Tasmania

The Council considered the report of the committee chaired by the Hon. Justice R.C. Wood released on 30 June.

The Council had written to the Premier advocating the Dunn Street site for a new building to house the art collection of the Tasmanian Museum and Art Gallery.

Cancellation of Government Grant

The Society had been informed by the Minister for Education and the Arts that the general grant to the Society, which had been $2500 in 1990, would not be available from the 1990–91 State Budget. The Council has protested to the State Government about the cessation of the grant, stressing the great contribution made to Tasmania by the Society.

Library

Mrs Beth Chalmers commenced duties as Royal Society librarian in February 1990 in a part-time capacity.

Mrs Penny Mele worked as part-time clerical assistant from January to June 1990. Mrs Mele then moved to the Circulation Section of the University Library.

Mrs Julie Cariaga, who worked in the Library from September to December 1989, returned as clerical assistant from July to December 1990.

400 visitors signed the register.

105 journals were recorded as being consulted in the Library.

80 journals were borrowed from the Library.

53 items were supplied through inter-library loan.

255 volumes were bound this year.

The use of the collection for inter-library loan purposes continues to be much lower than in the period prior to the introduction of charges for inter-library loans. The fact that we are part of the larger university system, for inter-library loans purposes, has meant the Society library has not been unduly inconvenienced as have many other small libraries over this period. The uniqueness of the collection is highlighted by these continued requests from all over Australia.

The card index for volume 123, 1989, of the *Papers and Proceedings* was completed and sent to the eight participating libraries. The production of a consolidated index for the sesquicentenary of the Society, in a printed format to cover volumes 89–125 (1955–91), has been planned. It would be timely to consider the format of the index after this period, as advances in technology provide the possibility of more efficient production and much greater accessibility.

To date, the second part of volume 124, 1990, the Curtis Volume, of the *Papers and Proceedings* has not been received from the printers. It is anticipated that the two parts will be sent out to the exchange partners in early 1991.

The listing of serials currently received by the Royal Society Library has been updated. This booklet has been widely appreciated by members and other special libraries.

Publications

Volume 124, part 1, of the *Papers and Proceedings* was published on 24 October 1990. It comprised the Annual Report and seven papers in the fields of geology, sociology and zoology. The papers, occupying a total of 90 pages, involved ten authors.

A major effort during the year was the preparation of volume 124, part 2, a part designed to honour the botanical work of Dr W.M. Curtis, AM. At the end of the year this part, which will contain a biography and 27 papers on botanical subjects, was almost ready to go to the printers. Drs A.E. Orchard and G. Kantvilas assisted the editors greatly in preparation of this part.

Mrs Alison Jones sub-edited the volume and Mrs June Pongratz prepared it for publication.

The Society is once more indebted to Dr Banks and Dr Smith for their dedicated editorial work.

World Heritage Area Symposium

The World Heritage Area Symposium, organised in association with the Department of Parks, Wildlife and Heritage, was held at the Sheraton Hobart Hotel on Saturday and Sunday, 3 and 4 November.

The organising committee was:
Professor J.B. Kirkpatrick (Chairman)
Ms J. Balmer
Dr M.R. Banks
Mr D.G. Hannan
Dr S.J. Smith
Mr L.E. Wall

Enrolments for the whole symposium were 192, with 45 enroling for single sessions.

The symposium commenced with the Senior Vice-President, Dr J.S. Rogers, introducing the Hon. Judy Jackson, Minister for Parks, Wildlife and Heritage, who opened the meeting, and then the Hon. E.G. Whitlam, who delivered the keynote address.

During the eight sessions, 27 papers were given and the proceedings closed with addresses by Dr B. Felmingham and Mr J. Everett and a summary by Professor J.B. Kirkpatrick.

Associated with the Symposium were displays of posters from the Department of Parks, Wildlife and Heritage, Department of Resources and Energy, a Students' Art Display, a display of Heritage Area photographs, a film night and displays by the Wilderness Society and Heritage Books.

Lectures

The following lectures were given at General Meetings during the year:

March — "The best and most practical mind: J.B. Bridgen as educator and economist 1921–30" Professor O.M. Rose, University of Tasmania
April — "A Tasmanian chemist's A–Z" Mr G.F. Allison, Allison Laboratories
May — "A humanist amongst scientists. Reflections on an anthropological study of the Walter and Eliza Hall Institute of Medical Research" Dr Lyndsay Farrell, The Friends' School
June — "Ultra violet light. Its effects on the health of humans with especial reference to skin cancers" Dr David A. Tilsley
July — "Neptune: from Galileo to Voyager" Mr Martin George, Queen Victoria Museum and Art Gallery
August — "The Ocean Drilling Program and Australia's involvement" Dr R. Varne, University of Tasmania
September — "The global imperative, a view from paper manufacturing and electricity businesses" Mr Brian Gibson
October — "The James Clark Ross Expedition" Mr Peter Boyer, Mrs Gillian Winter and Dr P.G. Quilty
November —"The mammals of South America" Professor John F. Eisenberg, University of Florida

The June meeting was held at the Clinical School Lecture Theatre, Royal Hobart Hospital, as the Tasmanian Museum was closed for tests for asbestos.

Northern Branch

Chairman	Dr E.V.R. Ratcliff
Vice-Chairman	Miss E.M. Bryant
Honorary Secretary	Mr C.B. Tassell
Honorary Treasurer	Mr B.A. Pike
Council Members	Mr E.J. King
	Miss M.C. Deacon

The Branch Council met three times during the year.

The following lectures were given at General Meetings:

March — "59th ANZAAS Congress" Dr D. McWilliams
April — John West Memorial Lecture (combined meeting with Launceston Historical Society at the Pilgrim Hall) Prof. C.M.H. Clark
May — "Museums at the end of the century" Mr C.B. Tassell
June — "19th century discovery of the planet Neptune" Mr M. George
July — "Dame Nellie Melba" (combined meeting with Launceston Historical Society at Bailey's Restaurant) Mr B. Lennard
August — "Weed is a four letter word" Dr C. Lamp
September — "Native and introduced worms" Dr T.J. Kingston
October — "The role of the engineer" Mr H. Wellington
November — "European Aboriginal — 30 years settlement" Mr N.J.B. Plomley
December — Members' Night
"Memories of Myrtle Bank" Mrs J. Sebbage
"Nature of Glothic" Dr E.V.R. Ratcliff
"Brunel's Atmospheric Railway" Mr B. Chamberlain
"Ecclesiastical extravaganza" Mr A.T. Orr

Nominees to Other Bodies

The Council re-elected Mr A.R. Neilson and Dr P.G. Quilty to serve a further term on the Board of Trustees of the Tasmanian Museum and Art Gallery. They report on the year's activities:

The Tasmanian Museum and Art Gallery continues to collect and safeguard the physical evidence of the natural and human heritage of Tasmania, together with relevant material from beyond the State and beyond Australia. Objects in the collections are preserved and studied, and are exhibited for the education and enjoyment of the public.

The 1990 State Budget provided $1 522 000 to the Tasmanian Museum and Art Gallery, an increase of only 4% over the allocation in the 1989 Budget. Of this, 81.5% will be spent on salaries and related costs, about the same as in 1989–90.

There has been a great change in the composition of the Board of Trustees during the year with four new members appointed by His Excellency the Governor. Mr J.E. Tomlinson, AO, a Trustee since 1980 and Chairman since 1987, was not re-appointed at the expiry of his term on 30 June 1990. Mr A.R. Neilson took over as Chairman in August. Ms J. Whittle, Mr A.M. Blow, Ms A. Maddox and Mr J.H. Holmes replaced Mr G.D. Brown, Mr A.G. Shott, Mr B.M. Thomas and Mr Tomlinson.

The CRESAP review of the Department of Education and the Arts, released in October, included recommendations on museums and these have been adopted by the Government. A working party is to be established to set the "parameters for future museum funding" for the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery. A recommendation that an entry fee be imposed at the West Coast Pioneer's Memorial Museum, Zeehan, was considered by a Conference of Managers set up by both houses of Parliament. A committee has been set up to report on how the Museum can become self-funding over the next three years.

The Museum Education Office has been abolished by the State Government. The Tasmanian Museum and Art Gallery was one of the pioneers in museum education in Australia. The first Education Officer was seconded from the Education Department in 1936. The position continued until 1948 when it lapsed until 1973 when a teacher was once more seconded to the Museum and Art Gallery. A second Education Officer, specifically to deal with art, was appointed in 1976. The Musbus Project, to take museum displays to country schools, was established in 1976 with the appointment of Mr Richard Verrall as the third Education Officer. In 1986 the Education Officers were reduced to two and in 1990 to one. The sole remaining Education Officer was Mr Verrall

who has been fully occupied with the Musbus project. He was informed on 30 November 1990 that his position at the Museum and Art Gallery was to be terminated as from the end of 1990.

The Musbus Project has established a national reputation for its innovative, interactive exhibits which have brought science to Tasmanian country schools.

In late 1990, staff of the Museum and Art Gallery, along with other members of the State Service, were offered redundancy packages. Five staff accepted redundancy and were replaced by people previously employed elsewhere in the Department of Education and the Arts.

In December 1989, a public meeting set up by a "Steering Committee for the proposed Art Gallery in Tasmania", under the chairmanship of the Honourable Justice R.C. Wood. The Committee reported to a public meeting on 30 June 1990 and recommended the Salamanca Quarry site as the place to build "The Salamanca Centre" to provide an Art Gallery, theatre/concert hall and accommodation for the Tasmanian Conservatorium of Music at a cost of $34 000 000. In addition, the Committee recommended that the art collection remain vested in the Trustees of the Tasmanian Museum and Art Gallery and that they should be charged with the trusteeship of the proposed Art Gallery. The Trustees have confirmed their strong preference for the Dunn Street site immediately adjacent to the present Museum and Art Gallery building.

On 5 June 1990, the Museum and Art Gallery was closed to the public and staff while tests for asbestos were carried out by the Department of Health. The level of fibres detected within the building was well below the maximum level set by the National Occupational Health and Safety Commission. The concern had arisen because of the presence of asbestos-cement tiles on the roof of the 1966 building on the corner of Davey and Argyle Streets. These have now been sealed.

During 1990, 110 486 people visited the Museum and Art Gallery, compared with 101 168 in 1989.

The number of visitors the the West Coast Pioneer's Memorial Museum at Zeehan was estimated at 98 7000 for 1989–90.

Temporary exhibitions shown included: *Vincent McGrath, Timeprints* (December 1989–January), *Kevin Connor Paintings and Drawings* (January–February), *University of Tasmania, First 100 Years* (February–March), *German Graphics of the 70s* (February–March), *Australia's Italians 1788–1988* (April), *The Smorgon Family Collection of Contemporary American Art* (April–May), *The Medland Drawings* (April–May), *Puppets* (May–July), *Donald Friend Retrospective* (June–August), *Lace* (July–August), *George Bornemissza's World of Beetles* (August–September), *Mylie Peppin Ceramics* (August–October), *Voyager Retrospective* (October), *Australian Printmakers* (October–December), *Another Day, Another Dollar* (November–January 1991) and *The Misses Hookey, Murphy, Oldham, Swan* (December–February 1991).

Temporary displays covered a wide range from cephalopods to a model of old Government House.

The trustees were left a very substantial bequest by His Excellency Sir James Plimsoll, AC, CBE, Governor of Tasmania 1983–87, who died on 8 May 1987. The estate is still to be finalised but a total of $551 628 has been received, together with a number of Australian works of art. The first purchase made with funds from the bequest was a model of old Government House, Hobart, made in 1837 by Francis Low for Jane, Lady Franklin.

On 24 May 1990, at auction in London, the Trustees purchased the following work: *John Glover, The River Derwent and Hobart Town, Painted on the Spot*, 1831 or 1832, on canvas, 50.8 × 71.1 cm.

The painting cost $A341 189 and this has been funded through the Art Foundation of Tasmania. Half the purchase price will come from the Sir James Plimsoll bequest and the painting will be a memorial to Sir James. A public appeal is underway to raise funds to reimburse the Foundation.

Dr A.E. Orchard was elected by the Council to serve the Board of Trustees of the Royal Tasmanian Botanical Gardens, but retired at the end of 1990. He has been replaced by Mr J.E. Tomlinson, AO. Dr Orchard reports on the year's activities:

The major activity during 1990 was the long-awaited establishment of a Tasmanian native plant garden. A bed just to the north of the duck pond and fernery was allocated to this purpose. Expressions of interest from persons and organisations interested in developing a landscape plan and planting regime for this area were called for early in the year, and, as a result of this, Mrs S. Corbett was engaged as Landscape Consultant for the project. She worked in the capacity of sub-contractor to Howrah Plumbing Pty Ltd which undertook the contract for construction.

To ensure the fullest possible liaison between the Landscape Consultant and the staff of the Gardens a sub-committee was set up under the chairmanship of Dr Orchard, comprising representatives from the Board of Trustees and the Heads of Section of the Gardens staff. The plan for the garden envisages a series of graded ecological habitats from rainforest and alpine types through dry sclerophyll and woodland to coastal and dry heathland areas. Each will be planted with a representative range of species and will be fully labelled with interpretative signs. The initial planting was completed in time for the Christmas/New Year holidays.

The Tasmanian native plant garden is intended to fulfil four main functions: to provide visitors and the Tasmanian public with an introduction to Tasmanian flora, to show ecological succession, to provide facilities for the *ex situ* conservation of rare and endangered species, and to conduct research into the propagation and cultivation of Tasmanian plants.

Stage III of the Technical Support Services Centre, including a multispan glasshouse, Gardens Supervisor's office, fertilizer storeroom and machinery store, was completed. Treasury has approved funds for the start of Stage IV in the new financial year. This will be the final stage and includes the fuel pumps, pot washing and storage building for seedling boxes, chemical storage building and a new boundary fence between Government House and the Gardens.

Under the minor works program, $50 000 was provided for repairs to the Fuchsia House, unipaving near the Easy Access Garden and a start on the Native Plant Garden. The Government Asset Maintenance Fund provided $11 000 to repair the stone steps near the pergola leading down to the lily pond and $10 000 to refurbish the Conservatory fountain.

The Tropical Glasshouse has ben re-landscaped by Nursery Staff and now includes representatives of many economic plants including *Macadamia integrifolia* (macadamia nut), *Carica papaya* (paw-paw), *Camellia sinensis* (tea), *Coffea arabica* (coffee) and *Cocos nucifera* (coconut).

Seeds of a Canberra specimen of stone pine (*Pinus pinea*) that originated in Turkey were planted in the Nursery. This species was the original Lone Pine of Gallipoli. Seedlings were planted by several RSL clubs in honour of the 75th anniversary of the landing at Gallipoli.

Transfer of records of the Living Plant Collection into the computer database has continued during the year. The database now contains more than 5000 records. Two major previously unrecorded areas, the Eucalypt section and the Tropical House, as well as many smaller areas, were mapped, recorded and entered into the database.

A start has been made on the collation and proper storage of the photographic collection and a collection of colour slides of soft-tissue plants unsuitable for pressing, such as roses and rhododendrons, has been commenced.

A number of special events and programs were run during the year. Fifty-five members of the public attended a rose pruning demonstration, three Plant and Bird Walks were attended by 450 people, and over 4000 visitors viewed a display of tulips and activities held in conjunction with the Dutch Tulip Festival. January in the Gardens was a major success with over 540 people participating in a wide range of activities. The Education Service conducted six classes on plant propagation techniques and a range of courses on environmental education, as well as the usual student visits.

Looking ahead, 1991 will be a year of restraint as Government financial resources contract. Like all other agencies the Royal Tasmanian Botanical Gardens will be operating on a very tight budget, but it is expected that basic services will be able to be maintained.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. In particular, the lecturers, the Government of Tasmania, the Department of Parks, Wildlife and Heritage, the University of Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are specially thanked for their help and co-operation.

We are grateful for the dedicated help given by members of the Council during the year.

J.S. Rogers
Senior Vice-President

D.R. Gregg
Honorary Secretary

11 February 1991

Royal Society of Tasmania
Balance Sheet as at 31 December 1990

1989			1990
51 013	Accumulated funds		60 192.28
126	Subscriptions in advance		530.00
	Trust funds:		
2163	• Clive Lord memorial Fund	2206.16	
4659	• A.N. Lewis Memorial Fund	4719.09	
2161	• Morton Allport Memorial	2222.18	
823	• A.A. Clark Bequest	846.04	
2222	• Joseph Milligan Bequest	2323.07	
3085	• R.M. Johnston Memorial Fund	3166.85	
1333	• Henry Oliver Bequest	1332.64	
3068	• W.H. Hudspeth Memorial	3091.01	
6561	• Life Membership Fund	6583.05	26 490.09
$77 214			$87 212.37

Represented by:

33	Cash on hand		33.00
	Cash at bank:		
7033	• General account	20 419.74	
4418	• Papers and Proceedings account	4577.34	
1017	• Clive Lord Memorial Fund	1037.83	
1415	• A.N. Lewis Memorial Fund	1452.44	27 487.35
860	Mortgage loan		860.00
2000	Commonwealth Treasury Bonds and Inscribed Stock (at cost)		2000.00
7000	Interest bearing deposits		7000.00
15 000	Library (at valuation for insurance)		15 000.00
32 598	Publications (at selling prices)		29 232.02
5840	Medals (at selling price)		5600.00
$77 214			$87 212.37

The Society owns works of art which have been donated over the years and which do not appear on the Balance Sheet. They are all housed in the Tasmanian Museum and Art Gallery and are covered by that organisation's insurance. At catalogue is available to members listing these works of art.

D.R. Gregg
Honorary Secretary

T.A.H. Knight, B.Bus. A.A.S.A.
Honorary Treasurer

Royal Society of Tasmania
Statement of receipts and payments for the year ending 31 December 1990

GENERAL ACCOUNT

Balance 1 January 1990		7032.85		
Subscriptions			Stationery	540.87
26 @ $20	5248.00		Postage	2591.14
105 @ $12	1260.00		Copying	3.20
17 @ $8	136.00		Library books & subs	2479.06
Other	808.00	7452.00	Papers & Proceedings	6801.75
Publication sales		6263.92	Secretarial fees	1680.90
Curtis volume donations		6493.00	Bank duties/charges	53.64
Interest		2155.93	Post box rental	150.00
Interest — other		131.91	Projector lens	250.00
Rent		783.90	Papers & Proceedings refund	38.00
Banks Medal sales		240.00	Attendant fees	912.75
Government grant		2500.00	Northern Branch	1500.00
World Heritage Symposium		9008.00	Insurance	360.52
Donation		100.00	Sundry	83.94
			World Heritage Symposium	4296.00
				21 741.77
			Balance 31 December 1990	20 419.74
		$42 161.51		$42 161.51

ACCUMULATION ACCOUNT

Balance 1 January 1990		51 013.39
Add	Increased cash at bank	13 604.05
		64 617.44
Deduct	Decreased valuation of publications and medals	3606.13
	Net transfer to Trust Funds	415.03
	Net increase in advance subscriptions	404.00
Balance 31 December 1990		$60 192.28

WHEN WERE THE WALLS OF JERUSALEM LAST GLACIATED?

by D.G. Hannan and E.A. Colhoun

(with two text-figures)

HANNAN, D.G. & COLHOUN, E.A., 1991 (20:xii): When were the Walls of Jerusalem last glaciated? *Pap. Proc. R. Soc. Tasm.* 125: 1–6. ISSN 0080–4703. School of Education, University of Tasmania at Launceston, Box 1214, Launceston, Tasmania, Australia 7250 (DGH); Department of Geography, University of Newcastle, Rankin Drive, Newcastle, NSW, Australia 2308 (EAC).

There is evidence to indicate that parts of the Walls of Jerusalem National Park have been glaciated on two occasions. No evidence of earlier glaciations has been found, although at least two older periods of glaciation have been demonstrated in adjacent areas.

During the last glaciation, the Rowallan Glaciation, there was an incomplete ice cover and a large ice window, centred on the West Wall–Solomons Jewels area, extended from Mt Jerusalem to Howells Bluff. Rowallan-age end moraines trace the limits of this glaciation and the main erosional effects are extensive knock and lochan landscapes. The previous glaciation, the Arm Glaciation, probably covered the entire region except for the higher parts of the West Wall.

The Rowallan Glaciation reached its maximum in the Mersey Valley before 13 400±600 years BP. Deglaciation of the upper Mersey Valley was complete before 9760 ± 720 years BP. The Arm Glaciation is likely to be older than 130 000 years.

Key Words: Walls of Jerusalem National Park, World Heritage, glaciation, Tasmania.

INTRODUCTION

The Walls of Jerusalem area was proclaimed a national park in 1981 and, with a large adjoining area, known as the Tasmanian Wilderness World Heritage Area, was nominated for World Heritage status in 1989. The Walls of Jerusalem National Park incorporates an area of 11 510 ha on the western margin of the Central Plateau (fig. 1). The boundaries to the north and south respectively are Deception Point and Pine River. Lake Ball and the plateau edge through Clumner Bluff and Howells Bluff form the western boundary, and an irregular eastern boundary exists some 5 km east of Mount Jerusalem (fig. 1). The Walls of Jerusalem are formed by high, near-vertical scarps of Jurassic dolerite. They include the West Wall south of Lake Salome, the East Wall below Mount Jerusalem and the Wailing Wall on the western edge of Jaffa Vale. The area is drained by the Fish River in the north, flowing into Lake Rowallan, and the Pine River in the south, flowing into the Derwent River catchment. Numerous lakes, particularly in the east, have caused the area to be called "The Land of Ten Thousand Lakes" (Jennings & Ahmad 1957). The highest peaks of the region are King Davids Peak (1470 m), Mt Jerusalem (1469 m) and Clumner Bluff (1458 m).

The bedrock is almost entirely Jurassic dolerite. The exceptions are a small sandstone and mudstone inlier of the Upper Parmeener Supergroup on the Temple (Forsyth 1989: 325) and possibly also in the lower part of the Fish River (Macleod *et al.* 1961). The dolerite has prominent vertical joints, one set of which strikes between 40° and 60°, the other between 115° and 125°. These joints are prominent both on air photographs and on the ground, due to intensive exploitation by glacial erosion. The superficial deposits are mainly glacial and periglacial sediments, which will be discussed later.

This paper is based on a regional survey conducted over the upper Mersey Valley and the adjacent part of the Central Plateau to the east. It aims to explain the glacial history of the western part of the Walls of Jerusalem National Park and, in so doing, answer the question posed in the title.

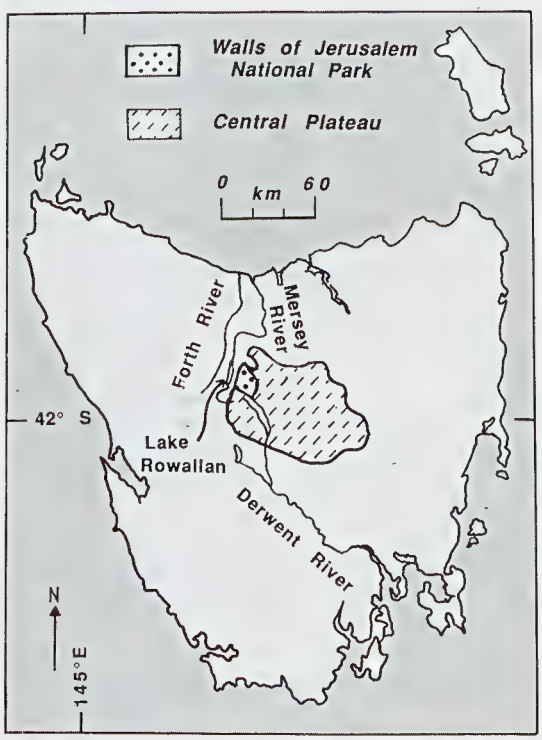

FIG. 1 — General location of the Walls of Jerusalem National Park and localities outside study area which are mentioned in the text.

PREVIOUS RESEARCH

Evidence of Pleistocene glaciation was first recognised in Tasmania by Selwyn & Gould in 1860 (Banks *et al.* 1987: 232). Recognition of glacial action in the Central Plateau came much later when Johnston (1893: 92) noted that the Central Plateau could contain an icecap capable of supplying "its western alpine valleys with numerous ice streams or glaciers". This was a complete change of mind from five years earlier, when he confidently stated that there was no evidence of post-Tertiary glaciation in Tasmania (Johnston 1888: 256). Nye (1921: 18) rejected the evidence for Pleistocene glaciation on the Central Plateau whilst acknowledging that evidence was frequently visible on the West Coast. Lewis (1932: 15) strongly advocated that the major lakes of the Central Plateau were formed by plateau glaciation and also suggested (1932: 32) that the icecap was sufficiently large to inundate the Mersey and Forth valleys.

Jennings & Ahmad (1957), in describing the glaciation of the western part of the Central Plateau, recognised only one glacial event. Other significant contributions of this paper were the identification of a major ice divide east of Mt Jerusalem and the delineation of erosional and depositional zones on the plateau. Geological mapping by Spry (1958), Ford (1960), Macleod *et al.* (1961) and Jennings (1963) all acknowledged the presence of an icecap on the plateau during the Pleistocene, which would have overflowed into the Mersey and Forth valleys. Derbyshire *et al.* (1965) rationalised the glacial history of Tasmania, restricted the ice-covered area and reduced the number of proven glacial events to one. Later Paterson (1965, 1969), Derbyshire (1971, 1972) and Derbyshire & Peterson (1971) emphasised the importance of sediments in the reconstruction of the glacial history of the Central Plateau region. They also presented stratigraphic evidence for more than one glacial event in the Mersey and Forth valleys.

Using the variable thicknesses of weathering rinds on dolerite clasts in till, Kiernan (1983) suggested three stages of glaciation in western Tasmania and extended them to include the Mersey and Forth valleys. Hannan & Colhoun (1987) provided stratigraphic evidence for the existence of three periods of glaciation in the upper Mersey Valley. They named the three glaciations from youngest to oldest as Rowallan, Arm and Croesus, providing for each a description of a basal till type section and an approximate age. Hannan (1989) presented statistical evidence for four periods of glaciation in the Mersey Valley but could not support it with stratigraphic evidence. Recently Kiernan & Hannan (1991) have provided stratigraphic evidence for four major ice advances in the Forth Valley.

Previous work suggests that there is evidence that the Walls of Jerusalem area should have experienced the effects of ice during three and possibly four periods of glaciation. It has also been hypothesised that in at least one of these periods a major ice divide existed immediately east of Mt Jerusalem. It is necessary to test such a probability by examining the field evidence for multiple glaciation of the area using the features of both glacial erosion and of deposition.

OVERVIEW OF THE GLACIAL HISTORY OF THE WALLS OF JERUSALEM NATIONAL PARK

In the Walls of Jerusalem National Park there is abundant evidence for previous glaciation. Both erosional zones and depositional zones of the last two glacial episodes are to be found within the park. The intensely jointed dolerite bedrock has been stripped of soil and weathered material leaving extensive areas of knock and lochan landscape (Sugden & John 1976: 194). In such areas there is little vegetation present. The depositional zones, by contrast, have a covering of light brown to red-brown soil developed on glacial deposits, which is capable of supporting a variety of vegetation communities, including a ground cover of grass.

Erosional landforms of the Rowallan Glaciation occur very widely within the ice limits shown on figure 2. The dolerite surfaces are relatively unweathered and have little or no soil cover. The landforms include roches moutonnées, whalebacks, ice-eroded basins, glaciated valleys, striations, overridden plateau edges and cirques. The area to the north and west of Zion Vale is a classic knock and lochan landscape. During the Rowallan Glaciation the highest peaks of the area were nunataks, e.g. Mt Jerusalem, Clumner Bluff and King Davids Peak.

However, the erosional landforms resulting from the Arm Glaciation are more weathered, and dolerite surfaces, though generally ice moulded, exhibit solution pans up to 600 mm in diameter. In contrast, solution pans are absent from erosional landforms of Rowallan age. The greatest area of Arm Glaciation erosional landforms occurs in the area known as Solomons Jewels and includes ice-eroded basins, roches moutonnées and whalebacks.

Basal till of the Rowallan Glaciation can be traced from the type section at Lake Rowallan to the Walls of Jerusalem area, where it has similar characteristics to that described by Hannan & Colhoun (1987) and Hannan (1989). The till is coherent, with almost equal proportions of matrix and clasts. The clasts are almost entirely dolerite and range in size from the smallest pebbles to boulders 2 m across. The colour of the till matrix is most commonly light brownish grey (7.5YR 7/1) or dull yellow-brown (10YR 5/3) (Oyama & Takehara 1967). A fissility can be observed at many locations, which suggests deposition as basal till. Hannan (1989: 58) showed that dolerite clasts in Rowallan tills have mean rind thicknesses of less than 1 mm (based on 50 clasts taken randomly from an outcrop). This is consistent with the field evidence from this study and has been a useful characteristic in the Walls of Jerusalem area for distinguishing Rowallan Till from more deeply weathered Arm deposits.

Glacial depositional landforms in the Walls of Jerusalem area are confined to terminal, lateral and ablation moraines. Moraines of Rowallan age are still intact and frequently have small lakes ponded behind them. For example, there is a series of end moraines in the valley between Mt Ophel and Zion Hill which have formed small moraine-dammed lakes, the largest of which is the Pool of Siloam. In places the moraine-dammed lakes have been filled with sediment, as is the case in the upper reaches of Wild Dog Creek. Depositional features from the Arm Glaciation are more dissected, such as the moraines in the vicinity of Lake Loane.

The presence of extensive block fields and very coarse thick scree deposits was taken as indicating areas ice-free during the Rowallan Glaciation as such features are most

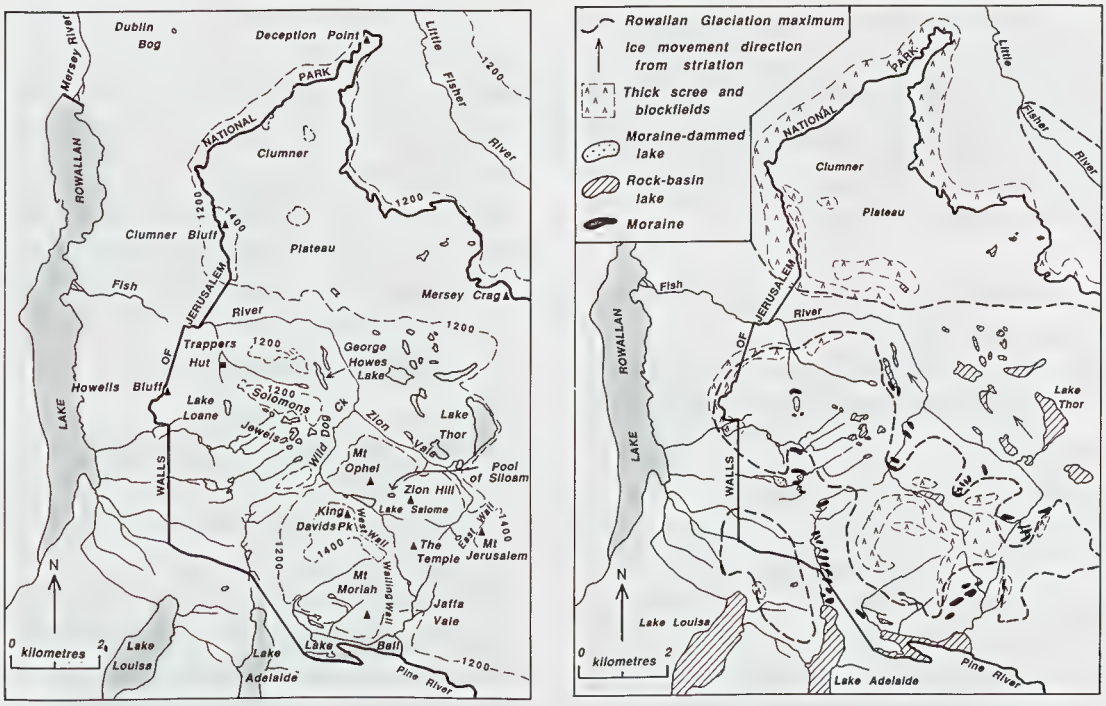

FIG. 2 — (A) Geographical localities, and (B) glacial landforms, sedimentary deposits and the Rowallan Glaciation limits for the western part of the Walls of Jerusalem National Park.

unlikely to have been developed during the brief deglaciation period of the Rowallan Glaciation. For example, the large areas of block field and scree indicate that no Rowallan Glaciation ice was present on the plateau behind Clumner Bluff. Similarly, massive scree slopes beneath the West Wall, and parts of the East Wall and the Wailing Wall, indicate that these areas were also ice-free during the Rowallan Glaciation. Figure 2 summarises the glacial features in the area.

AREAS GLACIATED DURING THE ROWALLAN GLACIATION

The Lake Adelaide Ice Lobe

Lake Adelaide (1055 m a.s.l.) and Lake Louisa (847 m a.s.l.) occupy two parallel depressions on the western edge of the Central Plateau and are separated by a dissected ridge with crests rising to approximately 1100 m a.s.l. Although neither of these lakes is in the Walls of Jerusalem National Park, they had great significance for the region during the Rowallan Glaciation.

The drainage in the area is deranged. Streams flow into Lake Adelaide from the east, west and north. About 20 m above and less than 1 km north of Lake Adelaide a stream in a well-developed valley flows southward out of a small lake and turns sharply west towards Lake Rowallan (fig. 2). A single stream flows from Lake Adelaide in a westerly direction into Lake Louisa.

The absence of till around Lake Louisa and the presence of scree slopes at its northern end suggest only a thin ice cover during the Rowallan Glaciation. This is further supported by extensive meltwater activity west of the lake.

By contrast, outcrops of the Rowallan Till are numerous around Lake Adelaide. They are found in the low bank on the northern foreshore of the lake, in creeks to the north of the lake and around the eastern edge of the lake. Hummocky end moraines exist up to 4.5 km north of the lake (fig. 2B). These end moraines provide evidence that Rowallan ice occupied the flat plain north of Lake Adelaide. The ice was not very thick because extensive screes occur to the east, down to an altitude of 1200 m on the slopes of the West Wall plateau. This suggests that 100 m south of the end moraine the maximum ice thickness would have been only 150 m.

At the Rowallan Glaciation ice limit it is likely that ice spilled into the Mersey Valley north of Lake Adelaide. A moraine complex 800 m north of the lake indicates that, for a prolonged period during the Rowallan Glaciation, ice was restricted to within 1 km of the lake. Extensive meltwater streams have carved deep valleys in a westerly direction off the plateau. Ice spillover from Lake Adelaide to Lake Louisa would also have occurred, mainly through a steep-sided channel at the northern end of the lake.

The Lake Ball–Jaffa Vale area

During the Rowallan Glaciation, ice occupied the present site of Lake Ball and at its maximum reached a height of approximately 1300 m on the slopes of Mount Moriah. The surface of the ice was continuous from Lake Ball to the Lake Adelaide depression. Moraines are visible in Jaffa Vale, where diffluent ice pushed up the valley. Extensive scree slopes on the northern part of the Wailing Wall and the southern slope

of the Temple show that the ice did not flow through the pass into the valley of Lake Salome at this time. The moraines which are visible in Jaffa Vale have a distinct northeasterly trend which coincides with the strike of prominent regional joints. It is likely that, since the ice in Jaffa Vale was stagnant, the moraines cover an ice-eroded landscape that has survived since the Arm Glaciation.

A stream flowing into Lake Ball has a barbed pattern due to glacial derangement (fig. 2).

Mt Jerusalem–Zion Vale–Fish River Area

There were two main zones of ice accumulation in the Walls of Jerusalem area during the Rowallan Glaciation. The first was the Central Plateau icecap, having its greatest thickness east of a line connecting Mersey Crag and Mount Jerusalem. Jennings & Ahmad (1957) and Derbyshire (1968) described a major ice divide occurring east of Mount Jerusalem. On the eastern side of the divide, the main volume of ice moved generally in a southeasterly direction. Northwest of this divide, small amounts of ice flowed towards the Mersey system, via Zion Vale, and to the valley of the Little Fisher River, north of the area discussed here. The second area of accumulation centred around two cirque-like landforms. One is occupied by Lake Thor and the other occurs approximately 1 km north in the headwaters of the Fish River. Ice from this second source area flowed into the main Mersey glacier via the Fish River valley.

The Central Plateau icecap has left abundant evidence of its presence east of Mount Jerusalem. An extensive sloping plain of smoothed, bare rock is present, with roches moutonnées indicating ice movement to the southeast. Little soil or vegetation exists and numerous depressions, many filled by lakes, ponds and marshes, are dotted across the landscape. On the northern slopes of Mount Jerusalem, the bare rock is striated in places and gives indication that ice also moved northwest and west from the main icecap. Screes beneath the East Wall are lower and thicker towards the south than in the north, where they were trimmed by ice flowing from the Central Plateau. End moraines and a moraine-dammed lake are present beneath the southern end of the East Wall.

A relatively small volume of ice, considering the size of the icecap, flowed past the northern end of Mount Jerusalem. Of this, only a small proportion spilled into Zion Vale. The main volume moved northwestwards, as indicated by striations and the orientation of roches moutonnées (fig. 2), through Lake Thor and the "cirque" at the head of the Fish River. The ice in Zion Vale produced three small lobes which projected into the core of the National Park. It achieved a maximum thickness of 110 m, as it barely overtopped the low divide into the valley of Lake Salome, leaving behind a series of end moraines and moraine-dammed lakes, including the Pool of Siloam. Downstream, ice flowed into the valley of the Fish River, rising to George Howes Lake. A small diffluent ice lobe extended up Wild Dog Creek. Little, if any, ice of Rowallan age flowed northwards onto the Clumner Plateau. The ice margin reached a height of approximately 1250 m before it was diverted westwards into the Fish Valley. A substantial meltwater channel flowed through the unnamed creek which enters the Fish Valley close to Trappers Hut. In the creekbed below Trappers Hut on the southern flank of the Fish Valley, till is found up to 950 m and scree slopes are trimmed off just above this level, at 980–1000 m. On the northern side of the river, the highest till outcrop is close to 1100 m, in the creek which flows from Clumner Plateau. On the Walls of Jerusalem walking track below Trappers Hut, there are many glacial features visible, such as lateral moraines (e.g. at 860 m and 980 m), meltwater channels (e.g. at 860 m) and kame terraces (e.g. at 950 m).

The Little Fisher River flows from the Central Plateau north of the Walls of Jerusalem National Park. Rowallan age ice spilled over from the central icecap and flowed about 5 km down the valley to the moraines which are evidence for the Little Fisher ice lobe. Ford (1960) mapped an area of "terminal moraines" in a similar locality. The moraines form low undulations in the landscape and cannot be traced for more than 30–40 m across the valley.

AREAS UNGLACIATED DURING THE ROWALLAN GLACIATION

The Clumner Plateau

The abundant scree deposits containing numerous large blocks of dolerite suggest that ice of the Rowallan Glaciation was absent from this plateau. It is very likely that ice of the Arm Glaciation penetrated the region, in particular into the broad valley behind Clumner Bluff which has a distinct U-shape, possibly the result of deepening by ice action.

Below the scarp of Clumner Bluff there are some very large blocks of dolerite suggesting that slabs of dolerite toppled from the main face. It is likely that the dolerite in this locality was removed from the scarp by slab failure, where a jointed dolerite column develops shears at the base and catastrophic failure occurs, causing the block to fall (Caine 1983: 138).

The East Wall–West Wall Area

The Temple, East Wall, West Wall, Mount Ophel, Zion Hill, Mount Moriah and Lake Salome were all ice-free during the Rowallan Glaciation. Evidence of this is provided by significant block stream development to the east of the col between the Temple and Zion Hill, which would have been the main avenue for ice from the Central Plateau into the area. Extensive screes occur at the base of the West Wall and East Wall. These thick coarse screes in the core of the Walls of Jerusalem National Park contrast with the relative dearth of scree within the limits of Rowallan age ice. The contrast suggests that the thick screes were developed over a long time and are unlikely to have been formed since the decay of the Rowallan ice. The valleys between these screes contain soils on thick deposits possibly derived from solifluction material. Around Lake Salome for instance there is up to 2 m of brown clay-rich material underlying poorly formed dark alpine humus soil. Such soil formation is not found in areas known to have been glaciated by Rowallan age ice.

Parallel ridges resembling moraines and striking towards Lake Salome from the pass between the Temple and the West Wall could be moraine remnants from the Arm Glaciation. Arm ice would probably have covered all of this area, with the possible exception of the higher parts of the West Wall.

Solomons Jewels–Howells Bluff Area

The Solomons Jewels area has an abundance of clearly defined glacial erosion features such as basin lakes, roches moutonnées and whalebacks. There are also a large number of dolerite ice-transported boulders and infrequent till outcrops. It is inferred that these are the result of the Arm Glaciation since some outcrops of till are weathered and the contained dolerite clasts have weathering rinds in excess of 1 mm. The presence of solution pans on the erosional landforms is also indicative of a long period of chemical weathering since ice erosion of the initial surface.

AGES OF THE GLACIATIONS

The minimum age of the Rowallan Glaciation in the Mersey Valley has been established from a ^{14}C date on charcoal at the base of a core taken from lake sediments behind the end moraine at Dublin Bog. The age is 13 400 ± 600 BP (SUA 2188) (Hannan & Colhoun 1987: 44). A basal ^{14}C date from cultural deposits in the upper Mersey Valley (Lourandos 1983: 39) of 9760 ± 720 (Beta 4757) indicates that the upper Mersey Valley was deglaciated by this time. Further evidence for the minimum age of deglaciation in the Walls of Jerusalem area comes from a ^{14}C date taken at a depth of 2 m, from a raised *Sphagnum* bog in Zion Vale below Mt Jerusalem. This produced an age of 8270 ± 270 years BP (ANU-5794) (Whinam *et al.* 1989:14). There is no local evidence which defines the onset of glaciation but in other parts of the state this has been estimated as 25 000 years BP (Colhoun & van de Geer 1986)

The Arm Glaciation is beyond the range of radiocarbon dating. Hannan & Colhoun (1987: 44) and Hannan (1989: 131) estimate an age in excess of 100 000 years based on relative weathering criteria from analysis of dolerite weathering rinds. Such an estimate indicates that the Arm Glaciation is likely to have preceded the last interglacial and therefore the deposits are probably more than 130 000 years in age.

CONCLUSION

The Walls of Jerusalem National Park contains abundant evidence of glaciation. The erosional landforms produced by the last period of glaciation, the Rowallan Glaciation, are relatively unweathered. As a result they are often observed cut into bare rock with little soil development or vegetation around them. Depositional landforms are little eroded and the end moraines have been used to plot the limits of the glaciation. The till deposits are largely unweathered. The shape of the ice cover during this time was complex, with the main feature being a large ice window in the centre of the national park. A number of short ice lobes, some diffluent, penetrated towards the core of the park but did not engulf the area. A major ice divide east of Mt Jerusalem was responsible for most of the ice flowing off in a southeasterly direction. A small proportion of ice flowed northwestwards into the Fish Valley and the Little Fisher Valley. The ice in the Fish Valley formed a major tributary of the main Mersey glacier. The ice in the Little Fisher Valley terminated some 5 km from the edge of the Central Plateau.

The Arm Glaciation would appear to have covered most of the Walls of Jerusalem National Park area, with the possible exception of the higher parts of the West Wall. Parts of the region forming the ice window during the Rowallan Gaciation still exhibit erosional and depositional features formed during the Arm Glaciation.

To answer the question posed in the title it would appear that most of the Walls of Jerusalem National Park was glaciated between 25 000 and 10 000 years BP. The central part of the park, from the West Wall to Solomons Jewels was ice free during this time and was probably last glaciated more than 130 000 years BP.

ACKNOWLEDGEMENTS

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REFERENCES

Banks, M. R., Colhoun, E. A. & Hannan, D. G., 1987: Early discoveries of the effect of ice action in Australia. *J. Glaciol.* 33 (114): 231–235.

Caine, N., 1983: *THE MOUNTAINS OF NORTHEASTERN TASMANIA.* Balkema, Rotterdam.

Colhoun, E.A. & van de Geer, G., 1986: Holocene to middle last glaciation vegetation history at Tullabardine Dam, western Tasmania. *Proc. R. Soc. Lond.* B227: 177–207.

Derbyshire, E.D., 1968: Glacial map of NW–central Tasmania. *Rec. Geol. Surv. Tasm.* 6.

Derbyshire, E.D., 1971: On the status and correlation of glacial episodes in southeastern Australia. *Search* 2(8): 285–288.

Derbyshire, E.D., 1972: Pleistocene glaciation of Tasmania: Review and speculations. *Aust. Geogr. Stud.* 10: 79–94.

Derbyshire, E.D., Banks, M.R., Davies, J.L. & Jennings, J.N., 1965: *A GLACIAL MAP OF TASMANIA. Roy. Soc. Tasm. Spec. Publ.* 2.

Derbyshire, E.D. & Peterson, J.A., 1971: On the status and correlation of Pleistocene Glacial Episodes in southeastern Australia. *Aust. J. Sci.* 2(8): 285–288.

Ford, R.J., 1960: The geology of the Fisher River area. *Pap. Proc. R. Soc. Tasm.* 94: 25–34.

Forsyth, S.M., 1989, Upper Parmeener Supergroup. *In* Burrett, C.F. & Martin, E.L. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ. 15.*

Hannan, D. G., 1989: Glacial history of the upper Mersey Valley. Unpublished M.Sc. thesis, University of Tasmania.

Hannan, D.G. & Colhoun, E.A., 1987: The glacial stratigraphy of the upper Mersey Valley. *Aust. Geogr. Stud.* 25(2): 36–46.

Jennings, I.B., 1963: *Middlesex, Tasmania.* Tasm. Dep. Mines 1 Mile Atlas Series, Expl. Rep. Sheet K/55-6-45.

Jennings, J.N. & Ahmad, N., 1957: The legacy of an ice cap. *Austr. Geogr.* 11(2): 62–75.

Johnston, R.M., 1888: *A SYSTEMATIC ACCOUNT OF THE GEOLOGY OF TASMANIA.* Government Printer, Hobart.

Johnston, R.M., 1893: The Glacier Epoch in Australia. *Pap. Proc. R. Soc. Tasm.* : 73–134.

Kiernan, K., 1983: Weathering evidence for an additional glacial stage in Tasmania. *Aust. Geogr. Stud.* 21(2): 197–220.

Kiernan, K. & Hannan, D.G. (1991): Glaciation of the upper Forth River catchment, Tasmania. *Aust. Geogr. Stud.* 29(1): 155–173.

Lewis, A.N., 1932: Note on the origin of the Great Lake and other lakes on the Central Plateau. *Pap. Proc. R. Soc. Tasm.:* 15–38.

Lourandos, H., 1983: 10,000 years in the Tasmanian highlands. *Aust. Archaeol.* 16: 39–47.

Macleod, W.N., Jack, R.H. & Threader, V.M., 1961: *Du Cane, Tasmania.* Tasm. Dep. Mines 1 Mile Atlas Series, Expl. Rep. Sheet K/55-11-52.

Nye, P.B., 1921: The underground water resources of the midlands Tasmania. *Underground Water Supply Bull.* 1, Tasmanian Dep. Mines, Hobart.

Oyama, M. & Takehara, H., 1967: *REVISED STANDARD SOIL COLOR CHARTS.* Japanese Research Council for Agriculture, Forestry and Fisheries, Tokyo.

Paterson, S.J., 1965: Pleistocene drift in the Mersey and Forth Valleys — probability of two glacial stages. *Pap. Proc. R. Soc. Tasm.* 99: 15–124.

Paterson, S.J., 1969: Pleistocene deposits at Parangana Damsite in the Mersey Valley — results of excavation and construction drilling. *Pap. Proc. R. Soc. Tasm.* 103: 57–61.

Spry, A., 1958: The Precambrian rocks of Tasmania Part 3, Mersey–Forth area. *Pap. Proc. R. Soc. Tasm.* 92: 117–142.

Sugden, D.E. & John, B.S., 1976: *GLACIERS AND LANDSCAPE A GEOMORPHOLOCIAL APPROACH.* Arnold, London.

Whinam, J., Eberhard, S., Kirkpatrick, J. & Moscal, T., 1989: *ECOLOGY AND CONSERVATION OF TASMANIAN* SPHAGNUM *PEATLANDS.* Tasmanian Conservation Trust Inc., Hobart.

(accepted 7 December 1990)

TASMANIPATUS BARRETTI GEN. NOV., SP. NOV. AND *T. ANOPHTHALMUS* SP. NOV.: TWO NEW AND UNUSUAL ONYCHOPHORANS (ONYCHOPHORA: PERIPATOPSIDAE) FROM NORTHEASTERN TASMANIA

by H. Ruhberg, R. Mesibov, D.A. Briscoe and N.N. Tait

(with four plates)

RUHBERG, H., MESIBOV, R., BRISCOE, D.A. & TAIT, N.N., 1991 (20:xii): *Tasmanipatus barretti* gen. nov., sp. nov. and *T. anophthalmus* sp. nov.: two new and unusual onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 7–10. ISSN 0080–4703. Zoologisches Institut und Zoologisches Museum, Universität Hamburg, Martin-Luther-King-Platz 3, D-2000 Hamburg13, Germany (HR); PO Box 431, Smithton, Tasmania, Australia 7330 (RM); and School of Biological Sciences, Macquarie University, Sydney, New South Wales, Australia 2109 (DAB & NNT).

Tasmanipatus gen. nov., Peripatopsidae Bouvier 1907, is characterised by eighteen dorsal plical folds on each body segment, in combination with a unique distribution of male crural papillae and a lack of pigmentation over all or most of the ventral body surface. The type species *T. barretti* sp. nov. is unique in relation to its combination of large size, uniform, patternless colouration, and well-developed crural papillae in both sexes. *Tasmanipatus anophthalmus* sp. nov. is unusual in lacking eyes and body pigmentation. The two species occur parapatrically in a small area in northeastern Tasmania. Their diagnostic features are described here.

Key Words: Onychophora, Tasmania, taxonomy, peripatus, velvet worm, *Tasmanipatus*.

INTRODUCTION

Two species of Peripatopsidae are currently recognised in Tasmania (Ruhberg 1985), the oviparous *Ooperipatellus insignis* (Dendy 1890) and the viviparous *Euperipatoides leuckarti* (Saenger 1869). Two new forms from the northeast of the state are described here and a new genus, *Tasmanipatus*, is erected to contain them. Detailed distributions and habitat preferences are described in Mesibov & Ruhberg (1991).

Specimens were collected in 1984–90 by one or more of the authors and their associates (for details, see Mesibov & Ruhberg 1991) and preserved in 70–75% ethanol or isopropanol. The bulk of the preserved material has been deposited at the Queen Victoria Museum and Art Gallery, Launceston, Tasmania. Specimens were loaned by the Museum for further study, and all type material will be stored there. Scanning electron micrographs were produced by HR in Hamburg.

RESULTS

Tasmanipatus gen. nov. (pls 1–4)

Type Species
Tasmanipatus barretti sp. nov., by original designation.

Etymology
The generic name is derived by combining *Tasman-*, referring to the geographic distribution of the new taxon, with *-patus*, the suffix of *Peripatus*.

Distribution
Tasmania, Australia. Only known from an area of approximately 800 km^2 in northeastern Tasmania. For species distributions see Mesibov & Ruhberg (1991).

Diagnosis
Tasmanipatus is a genus of Australian viviparous peripatopsid Onychophora with 18 dorsal plical folds per body segment, male crural papillae on leg pairs 6–12 (occasionally also on leg pairs 13 and 14) and a lack of pigmentation over all or most of the ventral body surface.

Differential Diagnosis
Tasmanipatus is distinguished from all other known peripatopsid genera on the basis of a unique combination of characters (for comparisons see Ruhberg 1985).

It is distinguished from South African *Peripatopsis* and *Opisthopatus* in having 15 pairs of legs and well-developed receptacula semines. Leg number and possession of basal foot papillae distinguish it from Chilean *Metaperipatus* and *Paropisthopatus*, and from New Guinean *Paraperipatus*. Presence of basal foot papillae and male crural glands allow distinction of *Tasmanipatus* from New Zealand *Peripatoides*.

Tasmanipatus is separable from all other Australian genera, except *Austroperipatus*, in its possession of basal foot papillae. In addition, it is distinguished from *Mantonipatus* in having 18 rather than 12 plical folds, and in lacking a characteristic pattern of several colours. From *Ooperipatus* and *Ooperipatellus* it is further distinguished by being viviparous, and from *Cephalofovea* (Ruhberg *et al.* 1988) by lacking a cephalic pit. *Tasmanipatus* and *Austroperipatus* differ in the presence of an ovipositor in females of the latter genus.

Description
Viviparous peripatopsid. Leg number constant within species, last leg pair well developed, with claws. Foot with 2 basal and 3 distal papillae. Pygidium (= anal cone) as long as, or longer than last pair of legs. Genital pore variable in form (pls 2, 4). Outer blade of mandibles lacking accessory tooth. Slime glands extremely ramified, more than in most other Peripatopsidae. *Male*: with crural glands corresponding with crural papillae, lying within the leg cavity; anterior accessory genital papillae on leg pair 15, with corresponding anterior accessory glands (= modified crural glands) lying within the body cavity as long, slender tubes; posterior accessory genital glands (= anal glands or modified segmental organs) opening

separately into V- or Y-shaped slits between genital pore and anus; anterior and posterior accessory glands coiled around each other; testes extremely long and twisted, unpaired genital tract long, spermatophores slender. *Female*: with paired ovaries which are long, flat, looped and closely attached to the pericardial septum; ovarial eggs exogenous; receptacula semines present; uterine embryos of about the same developmental stage, dorsal region of embryos supplied with a solid mass of yolk extending from the head to the anus.

Tasmanipatus barretti sp. nov. (pls 1, 2)

1938 *Ooperipatus insignis*, Barrett, *Vict. Nat.* 55: 11–12 (with two photographs).
1989 "Peripatus", Tait & Briscoe, *Aust. Nat. Hist.* 22: 574 (coloured photograph of live specimen).
1989 "Giant velvet worm". Local common name for this species.
1990 "Giant velvet worm", Mesibov, *Tasforests* 1991(July 1990): 53–56.
1991 "Giant velvet worm", Mesibov & Ruhberg, *Pap. Proc. R. Soc. Tasm.* 125: 11–16.

Holotype
♂, Tasmania, Evercreech Rivulet, EQ813163, leg. R. Mesibov, 7 Sep 1987 (size in preservative 36·4 mm; dissected). Collection of the Queen Victoria Museum and Art Gallery, Launceston.

Allotype
♀, same data as for holotype (23·3 mm, dissected).

Paratypes
2♀, same data as for holotype. 2♂, 2♀, Scamander River FQ046099, leg. RM, 17 Nov 1988. 2♂, 2♀, 1 juv., Salters Gully, FQ049003, leg. RM, 3 Nov 1988. 3♂, 1♀, 1 juv., Basin Creek, FQ036179, leg. RM, 29 Oct 1988. 5♀, Ericksons Road, EQ938253, leg. RM, 2 Sep 1987. 2♀, St Helens, Powers Rivulet (= Ericksons Road, EQ938253), leg. NN Tait *et al.*, 20 Feb 1987. 2♂, Ericksons Road, EQ938253, leg. RM, 11 Jun 1988, preserved 11 Jul 1988.

Etymology
The species is named after the Australian naturalist Charles Barrett (1879–1959). Barrett (1938) published two photographs of a live onychophoran with 15 pairs of legs which he identified as *Ooperipatus insignis*. The specimen "measured 1 1/4 inches in length, and was of a delicate fawn-brown colour" (Barrett 1938). It had been sent to Barrett in Melbourne from St Marys, Tasmania, which is near the known range of *T. barretti*. Unfortunately, the fate of Barrett's specimen, the exact locality of its capture and the name of the collector are unknown. We nevertheless believe that Barrett's is the first record of the onychophoran we name *T. barretti*.

First Collection
The first extant museum specimens were collected by RM at Terryvale Marsh (Ericksons Road, EQ938253) near St

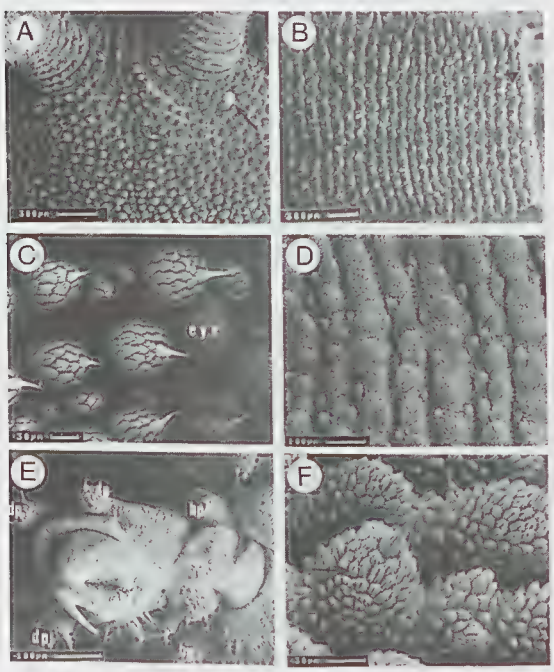

PLATE 1
Tasmanipatus barretti, *gen. nov., sp. nov. (A) SEM of the dorsal head with eye (arrow). (B) SEM of 18 segmental plical folds (between arrowheads). (C) SEM of eye and surrounding papillae. (D) SEM of plical folds with bigger primary and smaller secondary papillae. (E) SEM of foot with two basal (bp) and three distal (dp) papillae. (F) SEM of primary dorsal papilla with eight ranks of scales (arrow).*

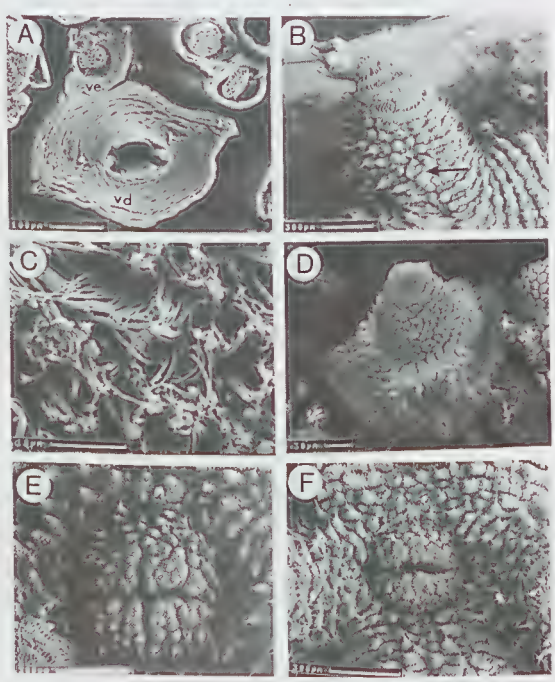

PLATE 2
Tasmanipatus barretti, *gen. nov., sp. nov. (A) SEM of male genital tract showing vasa efferentia (ve) and vas deferens (vd). (B) SEM of sixth foot of a male; showing position of a crural papilla (arrow). (C) SEM of spermatozoa from the vas efferens. (D) SEM of crural papilla of a female, extended. (E) SEM of a cruciform male genital pore. (F) SEM of a transverse male genital pore.*

Helens, on 3 Nov 1984, and were lodged at the Tasmanian Museum and Art Gallery, Hobart (acquisition number J1930).

Distribution
For detailed distribution see Mesibov & Ruhberg (1991: fig. 1).

Diagnosis
In life, dorsal surface pink-mauve with a darker median stripe, ventral surface mainly creamy-white. Distinct crural papillae in both sexes.

Description
Fifteen pairs of claw-bearing legs. Primary dorsal dermal papillae with 6–9 ranks of scales (plate 1F). Inner blade of jaw with 5–8 accessory teeth. Sex determination difficult without dissection (pl. 2E,F). Adults typically 35–40 mm long at rest, extending to 75 mm when walking. *Male*: with genital pore variable (e.g. transverse slit (pl. 2F) or cruciform (pl. 2E); anal pore slits distinct. *Female*: with distinct crural papillae on legs 6–12 in most paratypes, some females also with crural papillae on legs 13 and 14, and a homologue of the anterior accessory gland papilla on leg 15; only a pallid area evident in place of the male posterior accessory gland openings.

Tasmanipatus anophthalmus sp. nov. (pls 3, 4)

1989 "White Peripatus", Tait & Briscoe, *Aust. Nat. Hist.* 22: 579 (including coloured photograph of live specimen).
1989 "Blind velvet worm". Local common name for this species.
1990 "Blind velvet worm", Mesibov, *Tasforests* 1991 (July 1990): 53–56.
1991 "Blind velvet worm", Mesibov & Ruhberg, *Pap. Proc. R. Soc. Tasm.* 125: 11–16.

Holotype
♂, Tasmania, Elephant Pass, FP035875, leg. R. Mesibov, 17 Jul 1988 (size in preservative 16·2 mm). Collection of the Queen Victoria Museum and Art Gallery, Launceston.

Paratypes
1♂, same data as for holotype (size 17·2 mm; dissected).
1♀, Lower Marsh Creek, FP052883, leg. RM, 17 Nov 1988.
2♂, 1♀, Catos Creek, EQ965030, leg. RM, 30 Oct 1988. 2♂, 1♀, Lower Marsh Creek, FP052876, leg. RM, 2 Sep 1987.
2♂, Piccaninny Creek, FP020854, leg. RM, 19 Aug 1987.
2♂, Lower Marsh Creek, FP052876, leg. RM, 17 Aug 1987.
1♂, St Marys, Elephant Pass (= FP032890), leg. NN Tait *et al.*, 19 Feb 1987.

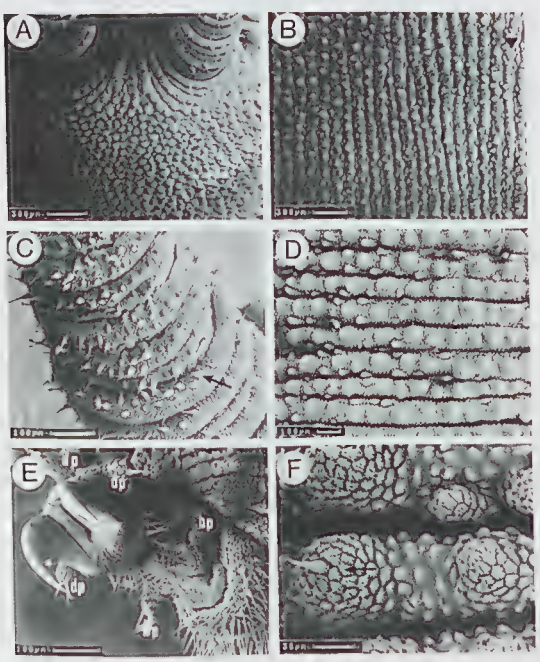

PLATE 3

Tasmanipatus anophthalmus, *sp. nov. (A) SEM of the dorsal head without eyes. (B) SEM of 18 segmental plical folds (between arrow heads). (C) SEM of ventral antennal base with sensillae (arrow). (D) SEM of plical folds with bigger primary and smaller secondary papillae. (E) SEM of foot with two basal (bp) and three distal (dp) papillae. (F) SEM of primary dorsal papilla with six ranks of scales (arrow).*

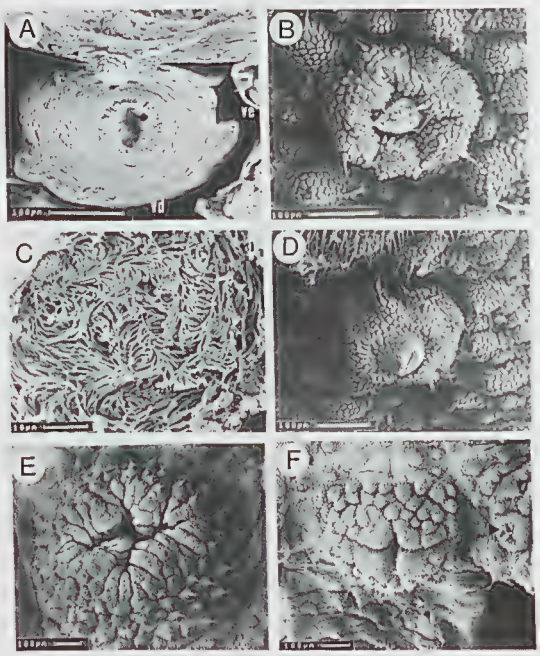

PLATE 4

Tasmanipatus anophthalmus, *sp. nov. (A) SEM of a male genital tract showing vasa efferentia (ve) and vas deferens (vd). (B) SEM of sixth foot of a male, showing invaginated crural papilla. (C) SEM of spermatozoa from the vas efferens. (D) SEM of semi-protruded male crural papilla from a twelfth leg. (E) SEM of a cruciform male genital pore. (F) SEM of a cruciform male genital papilla in another male, and anterior accessory genital papilla (arrowhead).*

Etymology
The species is named after its most characteristic feature, the lack of eyes.

First collection
T. anophthalmus was first collected by DBA, RM, NNT, K. Atkinson and R. Stutchbury at Elephant Pass and South Sister, near St Marys, on 19 February 1987.

Distribution
For detailed distribution see Mesibov & Ruhberg (1991: fig. 1).

Diagnosis
Entirely unpigmented skin; no darker median stripe. Tip of claws and entire jaws dark brown. No eyes. Distinct crural papillae in males only.

Description
Fifteen pairs of claw-bearing legs. Primary dorsal dermal papillae with 4–6 ranks of scales (pl. 3F). Inner blade of jaw with 5–6 accessory teeth. Sex determination easy without dissection (pl. 4E, F). Adults typically 25–30 mm long at rest, extending to 50 mm when walking. *Male*: with genital pore mainly cruciform (pl. 4E,F); anal pore slits not very distinct. *Female*: all paratypes without distinct crural papillae.

ACKNOWLEDGEMENTS

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REFERENCES

Barrett, C., 1938: A note on *Peripatus*. *Vict. Nat.* 55: 11–12.

Mesibov, R., 1990: Velvet worms: a special case of invertebrate fauna conservation. *Tasforests* 2: 53–56.

Mesibov, R. & Ruhberg., 1991: Ecology and conservation of *Tasmanipatus barretti* and *T. anophthalmus*, parapatric onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 11–16.

Ruhberg, H., 1985: Die Peripatopsidae (Onychophora). Systematik, Ökologie, Chorologie und phylogenetische Aspekte. *In* Schaller, F. (Ed.): *ZOOLOGIE, Heft 137*. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart: 1–184.

Ruhberg, H., Tait, N.N., Briscoe, D.A. & Storch, V., 1988: *Cephalofovea tomahmontis* n. gen., n. sp., an Australian peripatopsid (Onychophora) with a unique cephalic pit. *Zool. Anz.* 221: 117–133.

Tait, N.N. & Briscoe, D.A., 1989: *Peripatus* — up here for thinking? *Aust. Nat. Hist.* 22: 574–579.

(accepted 7 December 1990)

ECOLOGY AND CONSERVATION OF *TASMANIPATUS BARRETTI* AND *T. ANOPHTHALMUS*, PARAPATRIC ONYCHOPHORANS (ONYCHOPHORA: PERIPATOPSIDAE) FROM NORTHEASTERN TASMANIA

by R. Mesibov and H. Ruhberg

(with two text-figures and four plates)

MESIBOV, R. & RUHBERG, H., 1991 (20:xii): Ecology and conservation of *Tasmanipatus barretti* and *T. anophthalmus*, parapatric onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 11–16. ISSN 0080–4703. PO Box 431, Smithton, Tasmania, Australia 7330 (RM); and Zoologisches Institut und Zoologisches Museum, Universität Hamburg, Martin-Luther-King-Platz 3, D-2000 Hamburg 13, Germany (HR).

Tasmanipatus barretti and *T. anophthalmus* are parapatrically distributed in northeastern Tasmania with known ranges of about 600 km^2 and 200 km^2 respectively. Both species occur in wet sclerophyll forest. Both appear to tolerate habitat disturbance such as occasional bushfires, but are eliminated by forest clearing for agriculture or pine plantations. Both are found in forest reserves, and are to be further protected by a habitat management programme devised by the Tasmanian Forestry Commission.

Key Words: Onychophorans, northeastern Tasmania, parapatry, sclerophyll forest, conservation.

INTRODUCTION

Two rare and unusual species of peripatopsid onychophorans have recently been found in northeastern Tasmania. One species, *Tasmanipatus barretti*, locally known as the giant velvet worm, is the largest Tasmanian onychophoran. *Tasmanipatus barretti* extends to 75 mm in length when walking and is pink-mauve above with a white underside. It was apparently collected and photographed more than 50 years ago (Barrett 1938), although the first museum specimens, from the St Helens area, were taken in 1984. The second species, *T. anophthalmus*, the blind velvet worm, is eyeless, completely white and up to 50 mm long. It was first collected near St Marys in 1987 by a party led by N. Tait and D. Briscoe of Macquarie University, New South Wales. Both species are viviparous with 15 pairs of legs.

In this paper details of the distribution, habitats and conservation status of the two rare onychophorans are presented. Taxonomic descriptions are provided in an accompanying article (Ruhberg *et al.* 1991).

METHODS

The distribution maps in figures 1 and 2 are based on data from the following unpublished sources: (a) a report on a Tasmanian onychophoran survey by N. Tait and D. Briscoe, 1987 (8 localities); (b) a report on a *Tasmanipatus* mapping study by RM, 1987 (51 localities); (c) records of incidental collections by RM and P. Bell during a snail survey in the Douglas-Apsley area, 1988 (14 localities); (d) a report on an onychophoran mapping and conservation study in eastern Tasmania by RM, 1988 (34 localities); (e) records of collections by M. Luttrell (*T. anophthalmus* 1988, 4 localities) and C. Stanley (*T. barretti* 1988, 1 locality); (f) records of incidental collections by RM during a snail survey near Pioneer, 1989 (11 localities); (g) records of observations during a *Tasmanipatus* conservation study by R. Taylor and RM, 1989 (4 localities); (h) records of collections by HR and RM during a *Tasmanipatus* ecology study, 1989 (13 localities); and (i) records of incidental collections by RM during private field trips, 1984–90 (13 localities).

At each site visited in studies (a), (b), (d) and (h), onychophorans were hunted by gently breaking apart rotting logs and stumps. Less thorough inspections were made under intact logs and fallen limbs, under stones and in well-rotted accumulations of plant litter.

In their natural habitat, such as logs and stumps, onychophorans are easily missed, even by experienced observers. However, it is unlikely that the relatively conspicuous *Tasmanipatus* species were overlooked at sites where the cryptically-coloured *Ooperipatellus insignis* (Dendy 1890) was collected (see fig. 1).

Voucher specimens were taken at all but a few localities and were killed and preserved in 70–75% ethanol or isopropanol. In all cases the locality was recorded as a six-digit grid reference (e.g. FP028965 for a locality on St Patricks Head), which pinpoints the collecting site within a square 100 × 100 m. Apart from a small number of specimens required for further study, all voucher material has been deposited in Tasmanian museums (116 *T. barretti* and 47 *T. anophthalmus* at the Queen Victoria Museum, Launceston; three *T. barretti* and five *T. anophthalmus* at the Tasmanian Museum and Art Gallery, Hobart).

RESULTS

Distribution and Habitat

Tasmanipatus barretti ranges over about 600 km^2; the distribution area includes the Avenue/Scamander River, Golden Fleece Rivulet and George River catchments, the Dans Rivulet and Evercreech Rivulet catchments on the upper South Esk River and most of the major coastal creek catchments between St Helens and Chain of Lagoons (fig. 1). *Tasmanipatus barretti* occurs at about 20 m elevation within 0.5 km of the sea at Beaumaris and Four Mile Creek, and above 400 m elevation near South Sister and Mt Young. In the drier portion of its range, near the coast, it is found along

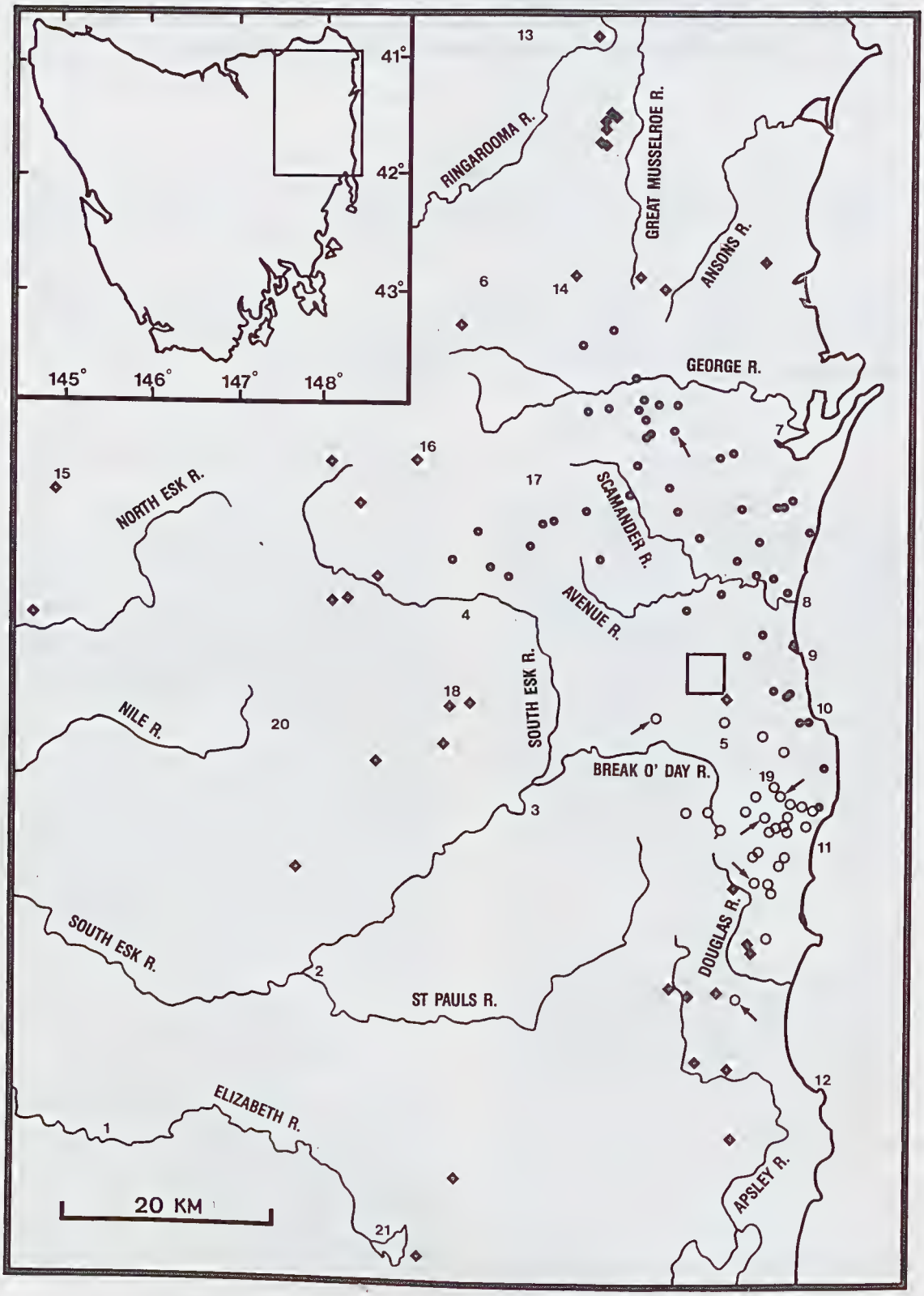
41°
42°
43°
145°
146°
147°
148°
RINGAROOMA R.
GREAT MUSSELROE R.
ANSONS R.
GEORGE R.
NORTH ESK R.
SCAMANDER R.
AVENUE R.
SOUTH ESK R.
NILE R.
BREAK O' DAY R.
DOUGLAS R.
SOUTH ESK R.
ST PAULS R.
ELIZABETH R.
APSLEY R.
20 KM
1
2
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PLATE 1
"Habitat island" along flowline on Skyline Tier, 2 km west of Scamander. Surrounding forest is almost entirely Eucalyptus sieberi. *"Island" vegetation is closed scrub of* Pomaderris apetala, Olearia argophylla *and* Bursaria spinosa. *This "island" is populated by* T. barretti. *White stick leaning against tree (arrow) is 1 m long.*

PLATE 2
Inside the "habitat island" of plate 1. Woody litter is moss-covered under 100% canopy cover. Ground fern is Polystichum proliferum. *White stick is 1 m long.*

flowlines on southeast and east-facing slopes, where it occurs in gallery forest or scrub, usually with a dense cover of *Acacia dealbata, A. melanoxylon, A. verniciflua, Bedfordia salicina, Olearia argophylla, O. lirata* or *Pomaderris apetala.* These gallery formations (pls 1 and 2) are well-defined "habitat islands" of wet sclerophyll vegetation among hills covered in open, dry sclerophyll forest largely dominated by *Eucalyptus sieberi.* Although *T. barretti* has only occasionally been found in open forest, it typically shelters in *E. sieberi* logs along flowlines, as well as in logs of the gallery species *E. globulus* and *E. viminalis.* North and northeast of Mathinna, it may be more or less continuously distributed through blocks of wet sclerophyll forest dominated by *E. obliqua* and *E. viminalis,* with understoreys varying from dense bracken fern to mature *Nothofagus cunninghamii* and *Atherosperma moschatum. Tasmanipatus anophthalmus* is apparently restricted to about 200 km^2 in the St Marys area (fig. 1). A large proportion of the population lives on the eastern face of Mt Elephant and along the mountain's east- and south-running flowlines. Other components of the population have been found in the four major coastal drainages immediately to the south of Mt Elephant, namely Wardlaws, Piccaninny, Stonyford and Cliff/Doctors Creeks. The remainder of the known distribution consists of scattered records in the Nicholas Range, on St Patricks Head, on the upper Denison Rivulet and upper Douglas River, and on a number of creeks feeding the upper Break O'Day River. *Tasmanipatus anophthalmus* occurs close to sea level on Little Marsh and Lower Marsh Creeks, and at over 800 m on South Sister. Throughout its range it is found almost exclusively in wet sclerophyll forest or scrub, whose structure and species composition varies greatly with such factors as elevation, aspect and fire history. On Mt Elephant it lives in a range of habitats from open forests of *E. delegatensis* or *E. sieberi* to deep gullies shaded by the treefern *Dicksonia antarctica;* while on lower Piccaninny Creek it occurs in *E. globulus* gallery forest.

Parapatry

Tasmanipatus barretti and *T. anophthalmus* are parapatrically distributed (fig. 1), with a presumed mixing zone about 20 km long. The mixing zone rises from near sea level north of Chain of Lagoons to about 500 m at Dublin Town. On Catos Creek (fig. 2), it appears to be less than 50 m wide, and at one point along this creek a specimen of each species was found in a single eucalypt log. The zone follows no topographic, vegetational or geological discontinuity and for most of its length traverses a deeply dissected, hilly landscape of Devonian granite and pyroclastics (Turner *et al.* 1984). Three creeks which cross the zone (Catos, Four Mile and Hughes Creeks) are known to have *T. anophthalmus* living in the upper part of the catchment and *T. barretti* in the lower.

FIG. 1 opposite: — Onychophoran localities in northeastern Tasmania. • = T. barretti, ○ = T. anophthalmus, ◆ = Ooperipatellus insignis. *Closely adjacent localities are indicated by a single symbol.* Tasmanipatus *localities marked with an arrow are also* Ooperipatellus *localities. Numbered towns and settlements: (1) Campbell Town, (2) Avoca, (3) Fingal, (4) Mathinna, (5) St Marys, (6) Weldborough, (7) St Helens, (8) Scamander, (9) Falmouth, (10) Four Mile Creek, (11) Chain of Lagoons, (12) Bicheno. Numbered features: (13) Mt Cameron, (14) Blue Tier, (15) Mt Barrow, (16) Mt Victoria, (17) Mt Young, (18) Tower Hill, (19) Mt Elephant, (20) Ben Lomond, (21) Lake Leake. Inset map shows location of main map. For detail within square north of St Marys, see fig. 2.*

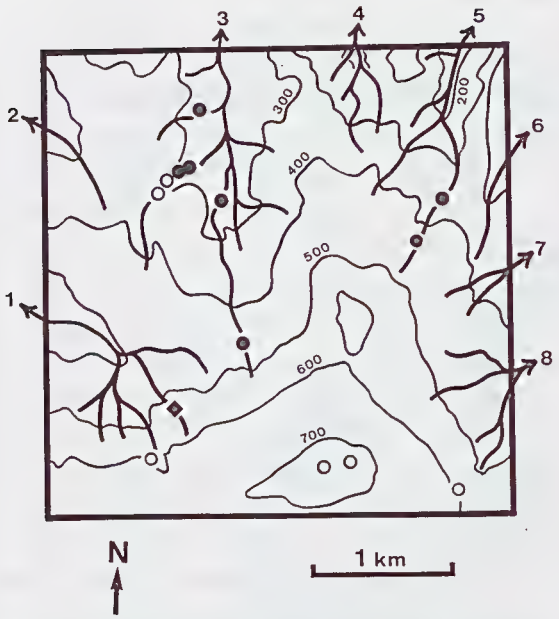

FIG. 2 — Onychophoran localities in the Dublin Town area, 6 km northwest of St Marys. • = T. barretti, O = T. anophthalmus, ◆ = Ooperipatellus insignis. *Roads and tracks omitted for clarity. Shaded areas are cleared land. The two hills at lower right are North Sister (above) and South Sister (below). Numbered creeks: (1) and (2) Scales Ck, (3) Catos Ck, (4) Bolpeys Ck, (5) Binns Ck, (6) Workers Ck, (7) and (8) Yorkys Ck. Map adapted from TASMAP 1:25 000 Dublin Town sheet; contour elevations are in metres.*

The oviparous onychophoran *Ooperipatellus insignis* occurs on both sides of the mixing zone. It was found in the same log as *T. barretti* at a locality near St Helens, and in the same log as *T. anophthalmus* at two localities near St Marys.

Microhabitat and Biology

Both *Tasmanipatus* species have most often been found in fallen logs of mature eucalypts (0.5–1 m in diameter) lying close to flowlines. Both species have been recovered from unburned, surface-charred and deeply burned logs; from bare logs lying in full sun and moss-covered logs under 100% canopy cover; and from intact, nearly cylindrical logs as well as logs collapsed to ground level. Although within the logs the onychophoran's immediate surroundings were invariably moist, the extent of decay ranged from unrotted wood (specimen under loose bark) to friable material and the clay-like "mud guts" associated with termite activity. At two sites *T. anophthalmus* was found under stones on shaded ground. *Tasmanipatus barretti* has been collected from the "litter cone" around the base of a standing, mature eucalypt, and from a pile of rotting bark waste about ten years post logging. Neither species has been seen to emerge from shelter at night, although it is believed that both species do so in order to disperse, mate and perhaps hunt. Young *T. barretti* of approximately equal size are sometimes found in close proximity in a single log, suggesting that a brood may shelter together for some time before dispersing.

The microhabitats occupied by the two species are rich in litter fauna, but neither feeding by, nor predation upon either species has been observed in the field. Associated fauna include triclad flatworms, the land nemertine *Argonemertes australiensis*, oligochaetes, isopods, amphipods, spiders, mites, the scorpion *Cercophonius squama*, harvestmen, centipedes, millipedes, symphylans, collembolans, cockroaches, termites, crickets, dipteran larvae, beetle larvae and adults (chiefly carabids, elaterids, lucanids and tenebrionids), ants, snails and occasional skinks. In captivity *T. anophthalmus* will eat killed termites and isopods (M. Luttrell, pers. comm.), and *T. barretti* will catch and eat live workers of *Porotermes adamsoni*, the common dampwood termite of Tasmania.

One specimen of *T. anophthalmus* gave birth to 12 live and two dead young shortly after her capture (M. Luttrell, pers. comm.); a second female produced 16 live young under similar circumstances. Birth of live young has not yet been observed in *T. barretti*.

Phoretic mites have been found on both *Tasmanipatus* species and will be described in a future publication.

Conservation

Impact

The geographical ranges of *T. barretti* and *T. anophthalmus* cannot be drawn precisely on a map, due to the small number of known localities and the evidently fragmented nature of the distributions. Nevertheless, an assessment of European impacts on their combined range has been attempted (Mesibov 1988), and a summary of that assessment is presented here.

From present-day vegetation patterns and a limited number of historical sources (travellers' accounts, local histories and early photographs), it seems likely that, prior to European settlement in the early 1800s, virtually the whole of the combined range was covered in eucalypt forest and woodland, the largest exception being the Break O'Day Plains, west of St Marys.

To date, only a small proportion of the forest cover has been removed and replaced by pasture, forestry plantations or town developments, three land uses which are incompatible with onychophoran survival. *Tasmanipatus barretti* has probably lost habitat to farms on Dans and Evercreech Rivulets and the George River, and along the coastal strip between St Helens and Chain of Lagoons, notably in the wide clearing at Falmouth. Plantations of Pinus *radiata* have almost certainly displaced *T. barretti* in the Evercreech Rivulet catchment and on Skyline and Loila Tiers, and possibly also at Saddleback Plantation near Mathinna. A significant area on the upper Break O'Day River flats has been developed as pasture; however, it is unclear whether these flats (which included the Break O'Day Plains) supported suitable habitat for *T. anophthalmus* prior to settlement. In the Mt Elephant area, the 5 km × 5 km block centred on the Tasman Highway/Mt Elephant Road junction (corners at FP010920, FP060920, FP060870 and FP010870) is known to be well-populated by *T. anophthalmus*; within this block about 12 km^2 have been alienated, of which 3.2 km^2 have so far been deforested.

Neither *Tasmanipatus* species seems to suffer from "edge effects". Juveniles and adults can be found within a few metres of a road clearing or grass paddock. Both species have been collected from selectively logged forest, and at

abandoned mining sites where the surrounding forest has recolonised disturbed ground.

The impact of fire is of particular interest. There is clear evidence of fire at all but one of the c. 100 sites where either species of *Tasmanipatus* has been collected. Many of these sites carry eucalypt regrowth dating from an intense establishment fire, or fires, which killed understorey vegetation. A number of collections of *T. barretti* and *T. anophthalmus* were from rot pockets within eucalypt logs with recently burned ends and blackened surfaces (pl. 3); *T. barretti* has been found in charcoal deposits within such logs. From this evidence it is inferred that *Tasmanipatus* populations will tolerate occasional burning of their forest habitat. However, within the ranges of both species there are forest patches where onychophorans were expected but not found, and where the vegetation pattern and a lack of large logs indicated a history of frequent or very hot burning. Hence, it is concluded that too-frequent burning or fires of too high intensity can eliminate *T. barretti* and *T. anophthalmus* from otherwise suitable forest habitat.

PLATE 3

A repeatedly burned Eucalyptus sieberi log on Skyline Tier, 2 km west of Scamader. Tasmanipatus barretti *was found sheltering in the wet (downhill) end of this log. White stick is 1 m long.*

Habitat management

More than 80% of the range of *T. barretti* is state forest, most of the remainder being partly cleared private property. The Tasmanian Forestry Commission has recently developed forest-management guidelines aimed at conserving *Tasmanipatus* in state forest (R. Taylor, pers. comm.). Fire damage is to be avoided in "habitat islands" of wet sclerophyll vegetation along flowlines and on south- and east-facing slopes, and wildlife priority areas (WPA) have been established in which onychophoran conservation has a higher priority than wood production. In the *T. barretti* range there are four such WPA, each of which contains relatively large blocks of wet sclerophyll habitat known to be populated by this species, the aggregate area being about 1700 ha. Protection from logging disturbance is also afforded in three forest reserves from which *T. barretti* has been recorded: Mathinna Falls (250 ha), Evercreech (52 ha), and Scamander (210 ha).

Tasmanipatus anophthalmus is to be conserved in the Mt Elephant WPA (1950 ha), which overlaps the 300 ha Lower Marsh Creek Forest Reserve. Fire protection for *T. anophthalmus* populations in state forest outside the Mt Elephant WPA is to be provided under the management guidelines referred to above.

The St Patricks Head State Reserve (150 ha) and the recently proclaimed Douglas-Apsley National Park (about 16 000 ha), both of which contain *T. anophthalmus* populations, are managed by the Tasmanian Department of Parks, Wildlife and Heritage. The Department has not yet announced plans specifically aimed at conserving onychophorans on crown land under its jurisdiction.

No formal protection is available for *Tasmanipatus* populations on private property.

DISCUSSION

Absence of Eyes and Pigmentation

The absence of eyes and pigmentation in *T. anophthalmus* are characters shared by the South African peripatopsid *Peripatopsis alba* (Lawrence 1931) and the Jamaican peripatid *Speleoperipatus speleus* (Peck 1975). However, the latter two species are troglobites restricted in each case to a single cave system, whereas *T. anophthalmus* occurs in forest litter throughout its known range. In this respect the Tasmanian species resembles the eyeless but pigmented peripatid *Typhloperipatus williamsoni,* found under stones in scrub jungle in the eastern Himalayan foothills (Kemp 1914).

Speculation that *Tasmanipatus anophthalmus* may be a cave-evolved species which has adapted to the forest habitat is encouraged by the fact that its distribution overlaps a cluster of Permian limestone outcrops in the St Marys area (Tasmanian Department of Mines 1984), and that the centre of its distribution, Mt Elephant, contains a small cave system (Matthews 1985). However, a 1988 search for *T. anophthalmus* in several holes and passages in the Mt Elephant karst was unsuccessful (S. Eberhard, pers. comm.).

Two confounding environmental factors need to be considered. The first is that the *T. anophthalmus* range roughly coincides with a high-rainfall anomaly. Moist onshore winds are cooled as they rise up the eastern faces of the hills near St Marys, producing cloud near the summits. Annual rainfall at Gray, on Mt Elephant's southwestern flank, is 1261 mm, compared to 1032 mm at St Marys and 724 mm in the nearby coastal town of Scamander (G. Leeds, Bureau of Meteorology, pers. comm.). Another feature of the orogenic rain is the intensity of individual rainfalls, which are believed to be the heaviest in Tasmania (Pilgrim 1987). The second factor is that the *T. anophthalmus* distribution overlaps that of talus and lag deposits of Jurassic dolerite on the Nicholas Range, St Patricks Head, Mt Elephant and the coastal hills running south from Chain of Lagoons (Tasmania Department of Mines 1984). Examination of this talus at Cheeseberry Hill (pl. 4) and Thompsons Marshes revealed *Ooperipatellus insignis* and other litter invertebrates in the first metre of depth. It is conceivable that *T. anophthalmus* is living micro-cavernicolously in the talus, but an assessment of the relative sizes of epigean and hypogean populations of this species would be an extremely difficult undertaking.

In summary, the authors are not convinced that the lack of eyes and pigmentation in *T. anophthalmus* are "cave adaptations", but are unable to explain either the origin or the ecological significance of this combination of features.

PLATE 4
Dolerite talus on Cheeseberry Hill, 4 km north of St Marys. White stick (arrow) is 1 m long.

Parapatry

The parapatry exhibited by the two *Tasmanipatus* species is likely to be a Holocene development, since eastern Tasmania is believed to have had a "glacial-arid" climate prior to about 11 500 BP (Macphail 1975). The presumed mixing zone may have arisen when the two species moved inland from neighbouring areas of recolonisation close to the present coastline. Because we have recorded only *T. barretti* in the lower reaches of catchments inhabited by both species, and because *T. anophthalmus* is likely to be carried downstream in logs during floods on those creeks, it appears that the former excludes the latter, and that the parapatric boundary may be moving upstream into the range of *T. anophthalmus*.

Management Recommendations

Habitat management as proposed by the Forestry Commission appears to be a practical means of conserving both *Tasmanipatus* species over most of their known ranges. The use of cool, fuel-reduction burning in dry forest to protect "habitat islands" of wet sclerophyll forest and scrub is supported. However, the two rare onychophoran species remain at risk of local extinction through catastrophic wildfire, and developments such as the new Four Mile Creek Road (linking Falmouth and Chain of Lagoons) and associated residential clearings are a potential source of fire threatening *T. anophthalmus* in the Mt Elephant area.

Tasmanipatus barretti and *T. anophthalmus* could also become locally extinct through overcollecting and destruction of microhabitats by collectors. As a conservation measure, investigators should borrow preserved material from existing collections at the Queen Victoria Museum and Art Gallery, Launceston or the Tasmanian Museum and Art Gallery, Hobart, rather than seek fresh specimens.

ACKNOWLEDGEMENTS

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REFERENCES

BARRETT, C., 1938: A note on Peripatus. *Vic. Nat.* 55: 11–12.

KEMP, S., 1914: Onychophora. *Rec. Ind. Mus.* 8: 471-492.

MACPHAIL, M., 1975: Late Pleistocene environments in Tasmania. *Search* 6: 295-300.

MATTHEWS, P.G. (Ed.), 1985: *AUSTRALIAN KARST INDEX, 1985.* Australian Speleological Federation, Inc., Melbourne: 7–8.

MESIBOV, R., 1988: Tasmanian Onychophora. Unpubl. report, Tasmanian Department of Lands, Parks & Wildlife.

PILGRIM, D.H. (Ed.), 1987: *AUSTRALIAN RAINFALL AND RUN-OFF: A GUIDE TO FLOOD ESTIMATION.* Vol. 2, Institution of Engineers, Australia, Sydney; map 1.9.

RUHBERG, H., MESIBOV, R., BRISCOE, D.A. & TAIT, N.N., 1991: *Tasmanipatus barretti* gen. nov., sp. nov. and *T. anophthalmus* sp. nov.: two new and unusual onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 7–10.

TURNER, N.J., CALVER, C.R., CASTLEDEN, R.H. & BAILLIE, P.W., 1984: *St Marys* 1: 50 000 series geol. atlas. Tasm. Dep. Mines.

(accepted 7 December 1990)

DISPERSAL AND ESTABLISHMENT OF HUON PINE *(LAGAROSTROBOS FRANKLINII)*

by A. Shapcott

(with seven figures and four tables)

SHAPCOTT, A.J., 1991 (20:xii): Dispersal and establishment of Huon pine *(Lagarostrobos franklinii). Pap. Proc. R. Soc. Tasm.* 125: 17–26. ISSN 0080–7403. Department of Parks, Wildlife and Heritage, GPO Box 44A, Hobart, Tasmania, Australia 7001 and Department of Plant Science, University of Tasmania GPO Box 252C, Hobart, Tasmania, Australia 7001.

Huon pine had a mast year in 1989 resulting in massive seedfall. It was found that Huon pine had extremely limited lateral seed dispersal by wind, although the chances of dispersal by water appear extremely good, due to its flotation capabilities. Green rosellas (*Platycercus caledonicus* Gmelin) were observed feeding on the seed and may play some role both as predators and dispersers of seed. A low percentage of successful germination was achieved and germination rate was slow. Seedlings appear to establish mostly on soil substrates but also occur on logs and trunks. Colonisation, even downstream, can take a considerable period of time and may partly explain the restricted distribution of Huon pine. The implications of these results for conservation and management are discussed.
Keywords: Huon pine, *Lagarostrobos franklinii*, Podocarpaceae, dispersal, seed germination, seedfall, colonisation.

INTRODUCTION

Huon pine (*Lagarostrobos franklinii* (Hook f.) Quinn) is a Tasmanian endemic conifer with restricted distribution in the southwestern part of the state. It is highly prized for its timber and has been subjected to logging for 180 years (Gibson 1986). Huon pine is extremely slow growing but long-lived (Francey *et al.* 1984). Its population numbers have been severely reduced due to human activities (Gibson 1986). An understanding of its reproductive, dispersal and establishment capabilities will contribute to assessments of its requirements for long-term viability and hence its conservation.

The extant distribution of most Huon pine stands close to rivers, creeks or drainage lines, where the species often forms a thin fringe on the banks (Peterson 1990), has led Millington *et al.* (1979) and Gibson (1986) to suggest that lateral dispersal of Huon pine is poor and that most dispersal is down rivers or moving water bodies. Where it occurs over wider areas, for example on river flats, on slopes and in limestone sink holes (e.g. Pedley *et al.* 1980), it is associated with moist, often boggy conditions, in locally fire-protected areas of high rainfall (Gibson 1988). Some evidence of expansion of Huon pine stands into previously fired areas has been recorded by Davies (1983) and Gibson (1986).

Huon pine is known to reproduce vegetatively as well as sexually (Millington *et al.* 1979). The vegetative reproduction observed offered only limited dispersal opportunities since propagules were limited to the extent of the root system or the length of the fallen trunk of the parent tree. Davies (1983) and Pedley *et al.* (1980) have speculated that fallen twigs may lodge, take root and shoot, and that these twigs may be dispersed by water, particularly by floods, to a suitable site. However, these seem to be rare events and most regrowth along rivers appears to result either from local vegetative reproduction or from seedlings.

Huon pine is mostly dioecious (Quinn 1982) and its reproductive activity is commonly thought to be episodic, with years of synchronised high reproductive activity (mast years) occurring approximately every 5–7 years. Such a mast year occurred in the 1988–89 season. This season also coincided with high reproductive activity in many other Tasmanian rainforest species.

Many authors (e.g. Read & Hill 1983, Harman & Franklin 1989) have suggested that logs and trunks may form major sites for seedling establishment. The lack of such suitable germination sites may consequently limit establishment possibilities.

This paper reports the results of an investigation into the pattern and timing of seedfall in a mast year in Huon pine. In addition, several vectors of seed dispersal were investigated, including lateral dispersal by wind or by the green rosella (*Platycercus caledonicus* Gmelin), and the potential for long-distance dispersal by water. The paper also describes experiments in germination under optimum conditions in the glasshouse and field observations differentiating the relative importance of habitat for seedling establishment. Finally, downstream colonisation by Huon pine at Condominium Creek is recorded and an approximate time frame for this process determined.

MATERIALS AND METHODS

Seedfall and Dispersal

Seed traps were set up at two sites in order to investigate seedfall and seed dispersal. One site was at Riveaux Creek (lat. 43°11'3"S, long. 146°40'E) near the Picton River, at the eastern limits of the distribution of Huon pine. The other was at Teepookana (lat. 42°14'S, long. 145°27'E) close to Macquarie Harbour, near the western edge of its distribution. The traps were of two types but both collected over a 1 m^2 area. The first type was made of galvanised iron, had a circular mouth and was funnel shaped. The second type was made of sailcloth and PVC piping and the funnel had a square mouth. Both had a sieved bucket attached to the base of the funnel to collect seed, and an open stocking leg was placed in the bucket to act as an appropriately sized filter and collection bag. The traps were mounted on wooden stakes. The seed was collected approximately monthly. The content of the stockings were air dried, if necessary, prior to sieving to

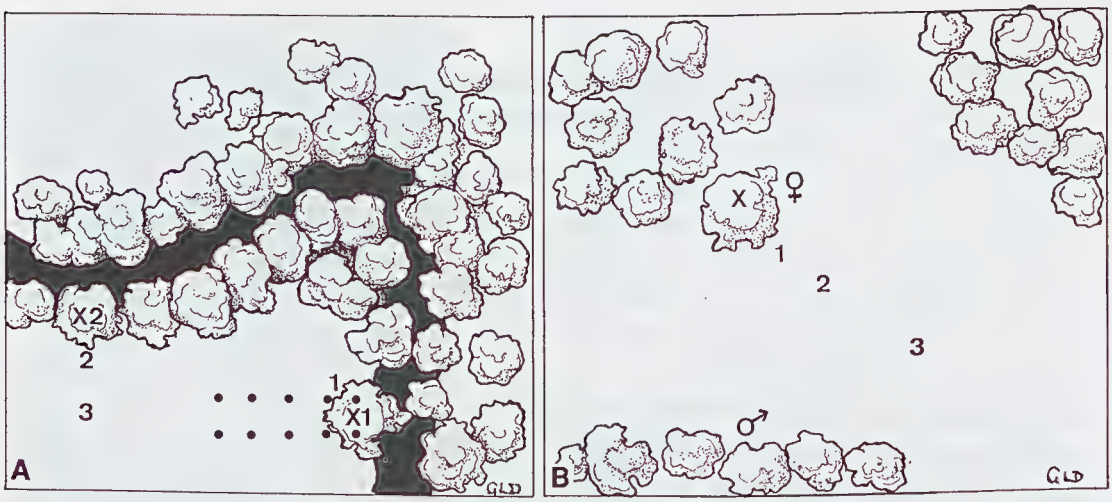

FIG. 1 — The spatial relationship between Huon pine seed traps, seed trees and Huon pine dominated forest at (A) the Riveaux Creek and (B) the Teepookana study sites. The positions of the seed traps are labelled by (1) (2) and (3). The site of quadrats for soil/litter samples are also shown (•). X – seed source tree at Teepookana. X1 – tree 1 at Riveaux Creek. X2 – tree 2 at Riveaux Creek.

remove as much extraneous material as was possible. This sieved sample was weighed and a sub-sample taken and weighed. The subsample (1–2 g) was then sorted and seed counted. Undersized seed was removed at this stage. Quantities of seed were extrapolated from these values.

At Riveaux Creek three traps were set up; two of these were located directly underneath the outer branches of each of two female cone-bearing trees. The third trap was located approximately one tree height (approx. 20 m) from both of the trees, as shown in figure 1A. The prevailing wind direction was mostly from tree 1 to trap 3 (i.e. from the southwest); tree 1 was in the position furthest upstream in the stand and was one of the large old dominant trees, while tree 2 was smaller. Both trees were heavily laden with seed-bearing cones.

At Teepookana three seed traps were set up at increasing distances from a fairly isolated seed-bearing tree in an area that was cleared and exposed. Trap 1 was located directly under the crown, while trap 2 was one tree height and trap 3 was three tree heights downwind of the tree (fig. 1B). The tree used as a source tree had a much smaller crown than the trees at Riveaux Creek.

Samples of the surface soil and litter were taken from two parallel transects from tree 1 at Riveaux Creek in November 1989. Quadrats, 0.24 m × 0.24 m, were marked and, using a trowel, scraped bare of surface soil, litter and moss, which were collected. These samples were later flushed with water through a sieve, air dried and resieved, and the number of Huon pine seeds was estimated in the same manner as for the seed traps. Quadrats were located at mid-canopy, at the edge of canopy, and then at 4 m intervals to 12 m (fig. 1A). Seed numbers were used to indicate lateral seed dispersal and the amount of seed still on the ground several months after seedfall.

Green Rosellas

Green rosellas (*Platycerus caledonicus*) feeding on Huon pine were noted on regular visits to Riveaux Creek. The feeding behaviour and trees visited were noted by direct observation and ground evidence. The period of feeding was recorded, i.e. first observation and monthly observations till activity ceased.

Seed Flotation

An experiment was carried out to investigate the period of time that Huon pine seeds can remain afloat. Three replicates were made, each containing 1000 seeds in a jar half-filled with tap water, with a porous cloth fastened to and covering the opening. The seeds were swirled approximately once per day, and every three to four days the water was changed by draining through the cloth and refilling. These processes ensured that the seeds were not floating due to surface tension and prevented algal development. The numbers of floating and submerged seeds were counted at regular intervals. The seeds used were collected from tree 1 at Riveaux Creek. Following the experiment, the seeds that remained floating, a sample of submerged seeds and a sample of similar aged air-dried seeds were subjected to a squash test in order to monitor embryo deterioration. Samples of submerged seeds and of air-dried seed were planted to test germination.

Seed Germination and Establishment

Fresh seed collected from a single tree at Riveaux Creek was used to set up a combination of germination experiments. Four replicates of 100 seeds were used for each combination of treatments. Three temperature treatments were set up as follows: constant 10°C; 20°C; and 10°–25°C diurnal fluctuation. Temperature treatments were conducted in growth cabinets with a 14-hour photoperiod; germination was also examined under glasshouse conditions with no artificial light. Seven physical treatments were carried out under all four temperature regimes (fig. 2): these were "untreated"; "damaged" by pricking with a needle; "soaked" in tap water for one week prior to sowing; "stratified for

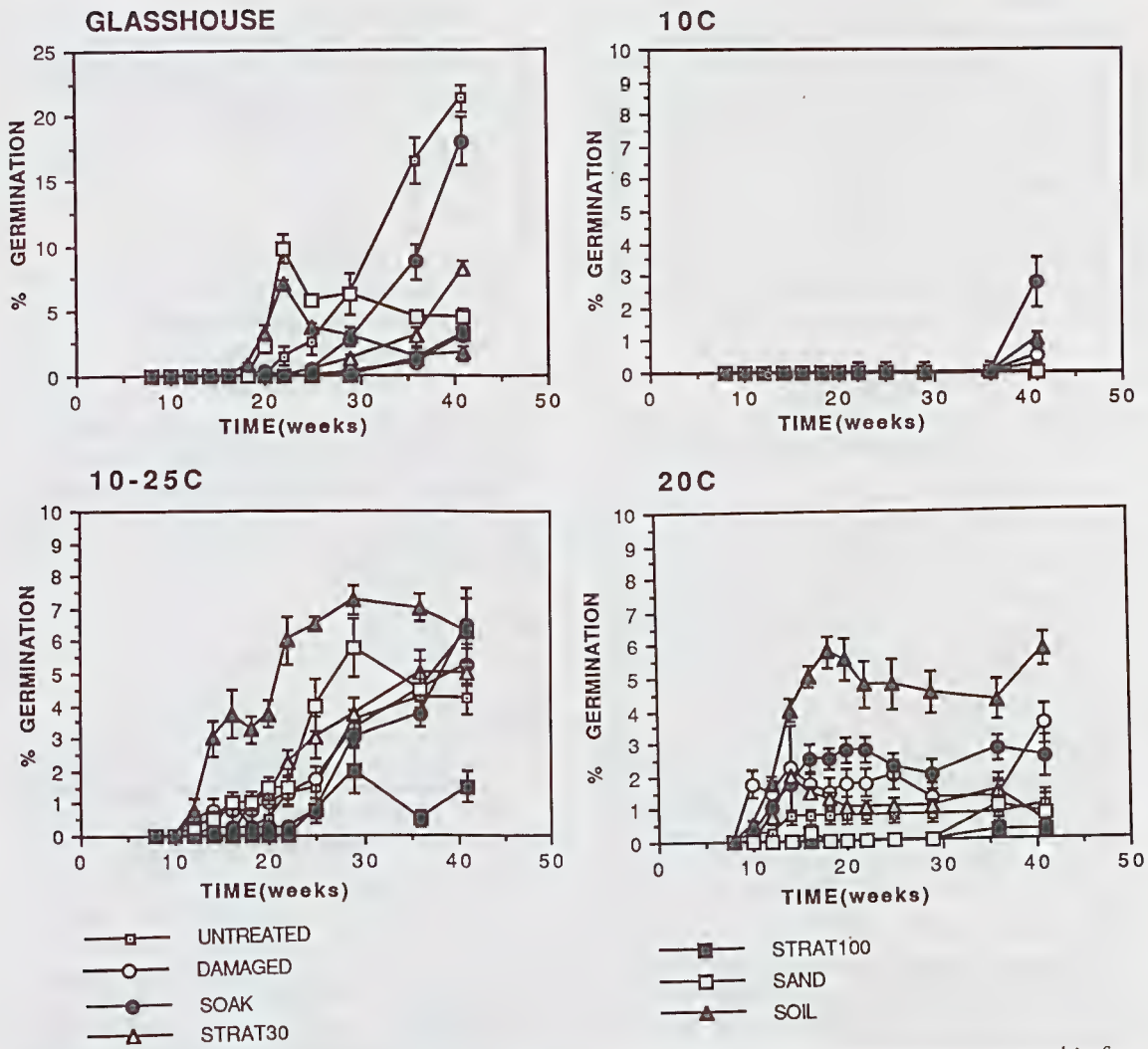

FIG. 2 — Mean percentage germination of Huon pine seeds over time (weeks), under seven physical treatments, and in four temperature regimes.

30 days" in a cold room (4°C); "stratified for 100 days"; sown in "sand"; sown in river "soil". All seeds were sown in clear plastic containers with lids. Except for the "sand" and "soil" treatments, they were sown on to filter paper overlying a layer of cotton wool. All seeds were dusted with "Thirium" fungicide prior to planting. Seeds were kept moist by regular watering with tap water.

The experiment ran from April 1989 until March 1990 and was scored fortnightly until week 22 and then as indicated (fig. 2). At each scoring the seeds were recorded in three categories: (1) open seed, i.e. the seed coat had split open; (2) emergence of root or hypocotyl from the seed; (3) cotyledons present and expanded. There was some mortality. The results of stages 2 and 3 were pooled for some analyses (fig. 2), since these represented an assessment of successful germination.

The site at Riveaux Creek was visited regularly (approximately monthly) to monitor other studies not included here. During these visits the site was monitored for the appearance of seedlings.

The number of seedlings established on logs or trunks (including logs and trunks of other species) and ground (soil, moss and rock) was recorded in the field from 19 sites, as part of a larger survey of stand structure and genetic variation (Shapcott 1991). At each site wide transects, which encompassed much of the stand, were surveyed for all Huon pine, as described below at Condominium Creek; the number, location and substrate of seedlings were recorded. Isolated individual stems less than 1 m tall were classified as seedlings but it was not possible in all cases to determine if these were actual seedlings or were vegetative growth from roots or trunks. Major excavations were not usually possible or desirable. As a consequence seedling numbers may have been overestimated.

Colonisation down Condominium Creek

Condominium Creek (lat. 42°57'20"S, long. 146°23'E) flows southwest from Mt Anne. The creek was surveyed

upstream from its intersection with the Scotts Peak Road until the first Huon pines (in this case seedlings) were found. From there all Huon pine plants and their location in relation to the creek were recorded and the following measurements taken; height, diameter and sex (if reproductively active). The stand was surveyed and sampled until it ended. There may have been trees further up the creek but these were not investigated. Nearly all of the Huon pine population occurs on the northern side of the creek, with more trees on the southern side only at the upper, older end of the stand. Buttongrass (*Gymnoschoenus sphaerocephalus* (R. Br.) Hook. f.) and *Leptospermum*-dominated heath dominates the southern bank in most places.

RESULTS

Seedfall and Dispersal

The trees at Riveaux Creek shed approximately 50 000 seeds/m^2, whereas at Teepookana seedfall was only 2200 seeds/m^2 (table 1). The seeds were collected for a longer period at Riveaux Creek and the trees had larger crowns, which may account for some of the discrepancy between sites. Both sites show a pattern of limited lateral seed dispersal. No seeds were found at one tree height distance at Teepookana and only eight were found over the six months of collection at this distance from trees at Riveaux Creek.

The quantity and timing of seedfall in traps 1 and 2 at Riveaux Creek are shown in figure 3 below. Seedfall started in February; the peak period of seedfall occurred around eight weeks later in early April, after which seed continued to fall at a reduced rate. The last seed counts were made six months from onset of seedfall, though the last of the seed was still dropping in December. The timing and amount of seedfall for the two trees at Riveaux Creek were similar.

The two transects designed to examine the seed stored in the soil showed similar patterns of seed dispersal, as indicated by the results from the seed traps. Although more seeds were collected from transect l, very few seeds were found at 12 m from the canopy edge (fig. 4).

The soil samples under the canopy contained approximately 20% of the seed numbers recorded in the seed traps on a per unit area basis. Although the soil seed numbers were obtained by a different method (i.e. not seed traps) and hence the results were not expected to be directly comparable, they still suggest that substantial seed loss has occurred in six months.

TABLE 1
Total of Huon pine seeds collected in February–November 1989

Site	Seedtrap no. and distance (m) from source tree	Seeds/m^2
Riveaux Creek	1 (0)	5.2×10^4
	2 (0)	4.8×10^4
	3 (25 & 15)	8
Teepookana	1 (0)	2.2×10^3
	2 (20)	0
	3 (60)	0

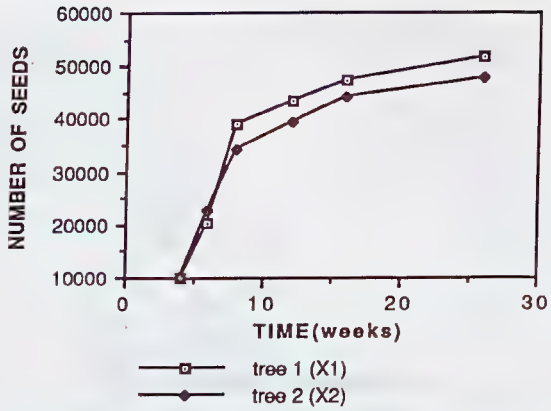

FIG. 3 — The cumulative Huon pine seedfall in two 1 m^2 seed traps in relation to time at Riveaux Creek.

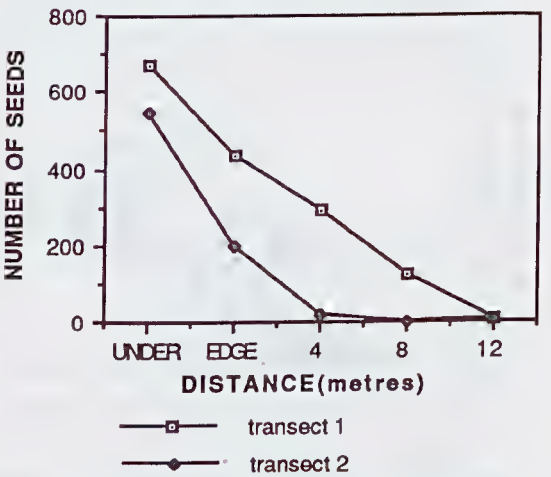

FIG. 4 — The number of Huon pine seeds in soil/litter samples (576 cm^2) against the distance along two parallel transects which extended out from under the canopy of Huon pine seed source tree (X1). (See fig. 1A.) (EDGE – edge of seed tree canopy (approx 4 m from first measurement): UNDER – under the middle of the seed tree canopy and at the start of the transect.)

Green Rosellas

Green Rosellas (*Platycercus caledonicus*) were first observed feeding on Huon pine at Riveaux Creek in April 1989. Sightings and evidence of their presence continued until December 1989. Prior to the initial observation no evidence of their presence was noticed. Such evidence consists of broken terminal branchlets found beneath the trees (Brown 1984). The commencement of feeding corresponded to the peak seedfall and the end of the warmer weather. All branchlets found on the ground until October bore mature female cones. This, together with direct observations, suggests that they were feeding on the seeds. From October 1989 (coinciding with maturation of young male cones and the end of the 1988–89 seed crop) green rosella activity seemed to move to the male trees where branchlets bearing mature male cones were found beneath male trees. Scattered evidence of feeding by green rosellas was observed at several sites from seedfall onwards during fieldwork. These observations confirm the suggestion by Gibson (1986) that green rosellas feed on

Huon pine. They appear to eat mature seeds and pollen. It is unknown what the effect of their gut is on the seeds. Green rosellas are known to carry food up to 100 m to feed (P. Brown, pers. comm.) and this could offer some lateral dispersal possibilities for Huon pine. There is some possibility that vegetative material (shoot tips) could also be dispersed in this manner.

Seed Flotation

Approximately 50% of the seed floated for one month and 5% stayed afloat for at least two months (fig. 5). If seed can stay afloat for such long periods of time, the potential distances for dispersal by water are enormous, provided viability is retained.

Squash tests for embryo deterioration indicated that seeds were usually still healthy after two months soaking (table 2) regardless of whether they remained floating or were submerged. Dry-stored seed from the same batch had a very high percentage of healthy embryos. Tests on submerged seed indicate that soaked seeds start germination marginally faster than dry-stored seed.

Germination and Establishment

In general, germination was low, with most treatments resulting in less than 20% overall germination and less than 10% of germinants progressing to the second (root) or third (expanded cotyledon) stages. The highest germination rate (22.75% total germination) was obtained after week 41 by untreated seeds in the glasshouse(fig. 2). The earliest germination started at week 10 in all temperatures except for 10°C. Very little germination occurred in the 10°C treatments and that which did occurred after week 36 (fig. 2). The earliest seedlings (stages 2 and 3) appeared in week 10 and were from the 20°C and damaged treatment combination. In the 20°C and 10°–25°C temperatures, the "soil" treatment was the most successful (fig. 2). Initially the "soil" and "sand" treatments did well in the glasshouse but towards the end of the experiment (weeks 36–41) the "untreated" and "soaked" treatments surpassed them. Stratification did not improve germination.

From the field records at Riveaux Creek, germination in the field began between week 29 and week 36 of the experiment (January/February) and corresponded to the rapid increase of germination in some glasshouse treatments. Germination in the field at Riveaux Creek the following year occurred during the same specific time period and the seed must have been from the same seed set. In general, these experiments have decreased the time before germination began, compared to the field situation. The effects of physical treatments on germination was not constant between the temperature treatments.

Approximately 20% of seedlings were found on logs or living trunks. Logs thus make up a sizeable part but minority of establishment sites (table 3).

TABLE 2
Percentage of viable embryos* in Huon pine seed used for the seed flotation experiment

	Number of seeds tested	Viable seeds %
Floating seeds	18	78
Submerged seeds	20	80
Air-dry stored seeds	100	99

* Determined by squash tests.

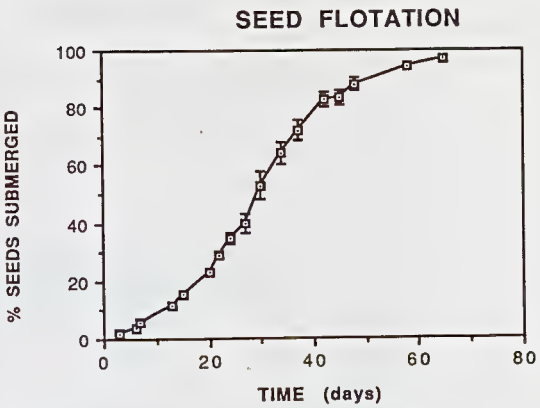

Fig. 5 — The percentage of seeds no longer floating versus time. The percentages are mean values of three replicates of 1000 seeds, the standard error bars are indicated.

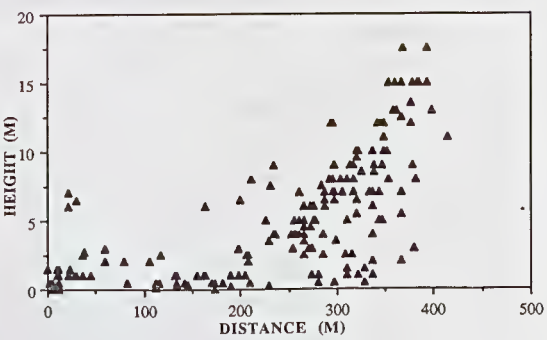

FIG. 6 — The height of Huon pine plants is plotted against the distance up the Huon pine transect (fig. 7). Each point represents a Huon pine plant. Distances as in figure 7.

Colonisation down Condominium Creek

Figure 7 illustrates the relative size and abundance of Huon pine up Condominium Creek. Small seedlings and suckers were found, mostly along the bank, from the first occurrence. However, there is a distinct size-class gradation from taller trees upstream to smaller ones further down (figs 6 and 7). If conservative age estimates are made from diameter measurements (Gibson 1986) it can be estimated that colonisation to 400 m downstream has taken at least 200 years.

TABLE 3
Comparison of number of huon pine seedlings found on different substrates

Site	No. on logs or trunks	No. on soil, sand or rock	Total	Area sampled (m^2)
Newall	9	12	21	4560
Stanley	14	65	79	2100
Greystone	20	29	49	1200
Pine Creek	0	13	13	4800
Riveaux Creek	185	2	187	1220
Denison	10	4	14	3060
Gordon	40	0	40	200
Teepookana	1	5	6	3936
Frenchmans Cap	22	0	22	216
Picton	88	0	88	1150
Pieman	20	4	24	6682
Gilbert Leitch	5	12	17	1196
Anne	8	0	8	880
Tahune	71	41	112	1092
Condominium Creek	71	1	72	6210
Huon	138	4	142	695
King	12	0	12	975
Junction Creek	25	23	58	2565
Eagle Creek (Gordon)	85	27	112	2042
Total	824	242	1066	44779
Total % of seedings	77.3	22.7		

TABLE 4
Summary of seedfall data* from a variety of high yielding tree species (converted to the number of seeds/m^2)

Species	Seed no./m^2	Author
Dendrocalamus strictus†	1.3×10^5	Janzen (1976)
Lagarostrobos franklinii‡¶	5.0×10^4	Shapcott
Nothofagus cunninghamii¶	1.3×10^4	Howard (1973)
Athrotaxis selaginoides†¶	7.7×10^3	Berrigan (1982)
Eucalyptus delegatensis¶	4×10^3	O'Dowd & Gill (1984)
Macrozamia communis†	3.5×10^3	Ballardie & Whelan (1986)
Picea sitchensis/ *Tsuga heterophylla*	3.5×10^3	Harman & Franklin (1989)
Atherosperma moschatum¶	1.2×10^3	Hickey *et al.* (1982)
Dacrydium cupressinum†	1.2×10^3	Ogden (1985)
Eucryphia lucida¶	8×10^2	Hickey *et al.* (1982)

* Collected from the literature.
† Mast seed years.
‡ From the present study.
¶ Tasmanian species.

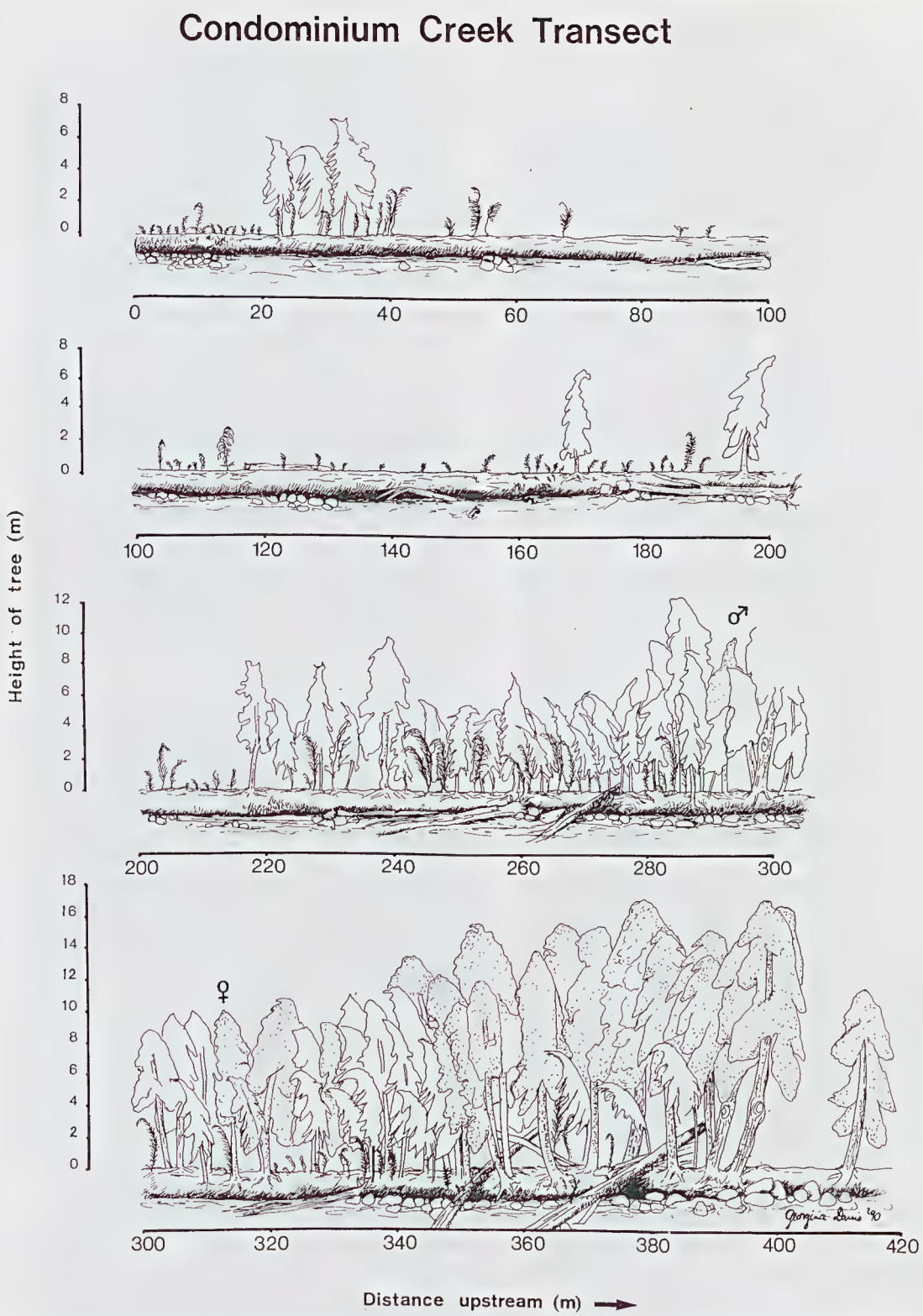

FIG. 7 — The illustration represents a transect of the Huon pine population up Condominium Creek from 0 m to 420 m; 0 m represents the first occurrence of the Huon pine upstream of its intersection with the Scotts Peak Road and the stand came to a natural end 420 m from this point. The occurrences of the first reproductively active male (♂) and female (♀) trees up the transect are indicated. Only Huon pine plants are represented and, except in the tallest denser section, all plants recorded are illustrated.

DISCUSSION

Seedfall

The results indicate that Huon pine can produce very large numbers of seeds in mast years. The 5×10^4 seeds per m^2 compares with some of the higher densities of seedfall reported for other species from a variety of countries in the literature (table 4). The seedfall is greater than that recorded for the other Tasmanian species reported.

Mast seeding is characteristic of the Podocarpaceae as well as many other tree species (Norton *et al.* 1988). Many authors (e.g. Janzen 1976) suggest that climatic conditions may trigger a mast year and in New Zealand hot dry summers are thought to be a climatic cue (Silvertown 1980, Ogden 1985). Ogden (1985) suggested that periodic massive seeding may be a strategy for keeping safe sites fully stocked with long-lived seedlings and may also provide enhanced opportunity for long-distance dispersal and colonisation of sites which are spatially and temporally restricted. An alternative hypothesis suggests that synchronous seeding acts to satiate seed predators with an over-abundance of seed and, in addition, prevent predator population growth in intervening years (Janzen 1976, Silvertown 1980, Wardle 1984, Louda 1989). If predator satiation is a factor, trees out of synchrony will be strongly selected against, due to a build up in predator numbers during the mast year (Janzen 1976, Silvertown 1980).

Little is known of seed predators of Huon pine, although the green rosella observations are consistent with predator satiation, since the observed feeding seems to have left large quantities of seed (table 1). The number of birds gathering and feeding on Huon pine at Riveaux Creek was not large and there was limited evidence of green rosella activity in other stands. However, at Riveaux Creek the Huon pine seeds and pollen seemed to provide food over winter, when other seed may have been less abundant.

The climatic conditions previous to the 1988–89 masting year do seem to fit the New Zealand hot dry summer climatic cue. Masting in that season was also observed in the two Tasmanian *Athrotaxis* species. The development of a consecutive second mast year during 1989–90 in Huon pine is interesting. Consecutive mast years have also been recorded in New Zealand podocarps (Norton *et al.* 1988, Ogden 1985). Good fruiting was recorded for the other Tasmanian podocarps in the 1989–90 season in Tasmania (P.B. Tomlinson, pers. comm.). Continued monitoring indicated that very little seed was set, suggesting the female cone development was out of synchronisation at Riveaux Creek. Very few female cones developed the following season.

The seed matured and was shed over an extended period of time. It has been suggested that an extended period of seed/fruit maturation may be advantageous to animal (e.g. bird) dispersal of seed (Janzen 1983). As Janzen also pointed out, although much seed is likely to be destroyed in the gut, some may pass through intact and, depending on the habits and nature of the animal, may be dispersed to favourable sites for germination. Green rosellas may act as both predators and dispersal agents of Huon pine, and the pattern of its seedfall may reflect the minimising of predator effects by masting and maximising of dispersal by an extended maturation and seed-shedding period.

Dispersal

The lateral dispersal by wind is very limited, as evidenced by the seed trap and soil/litter data. The dispersal is similar to other podocarps (Norton *et al.* 1988) but less than that recorded by Hickey *et al.* (1982) for other Tasmanian rainforest species. This data supports the view that the limited lateral dispersal of Huon pine increases the time taken for colonisation of surrounding vegetation (Gibson 1986, Millington *et al.* 1979, Davies 1983). Given that *Bioclim* data (Gibson 1986) suggests that Huon pine could have a broader habitat range at present, poor lateral dispersal may be an important limiting factor. However, the Condominium Creek example demonstrates that downstream colonisation is slow even where dispersal of seed is good, and many areas of superficially suitable habitat may not be colonised by seed. Other authors have speculated, however, that on larger rivers, vegetative material carried by flood waters may disperse the species (Pedley *et al.* 1980). My studies have indicated that most regeneration is due to vegetative growth from root suckers or fallen or submerged limbs or seedlings. Only very rarely was there evidence of vegetative propagation or potential for it from separated shoots or branches. Davies (1983) noted the patchy Huon pine occurrence on the Denison River and suggested it may coincide with limestone rock types. However, rock types do not explain the conditions at Condominium Creek. Fire may partly explain the pattern of Condominium Creek but other factors such as seedling establishment require further examination.

The amount of seed retrieved from soil samples indicates the size of the soil seed bank and gives an indication that most seed was lost from the soil within a few months of falling. Baker (1989) has found that seed of some species from moist habitats survives better if kept moist. It is possible that Huon pine seeds remaining in moist locations could remain viable, and the seeds may germinate over an extended period of time. Thus, in non-mast years, seeds from the previous season may germinate when favourable conditions occur. There is some evidence for this, since small numbers of cotyledon-size seedlings were found at several sites during the study. These must either have resulted from limited "off season" seedfall, remained at cotyledon stage for several years or germinated after the major seedfall and subsequent germination "wave".

Germination and Establishment

The germination experiments demonstrated that germination can occur over an extended period of time. The low germination success may be due to inviability and the complex factors affecting dormancy. The germination in the glasshouse experiments began considerably earlier than in the field, probably due to the warmer growth conditions. The success of the "soil" treatment suggests that elements present in this medium may enhance germination. The success of the "soaked" seeds also indicates the role water may play in enhancing germination. The germination success of seeds soaked for two months during the flotation experiment supports this view and may suggest that seeds which are water dispersed may have a greater chance of successful germination than seeds laterally dispersed by wind. The germination in the field at the same time over two consecutive years and the germination with natural light conditions in the glasshouse

indicate that daylength may trigger a break in dormancy.

The flotation capabilities of Huon pine seeds shown in figure 5 appear far greater than those reported for other podocarps (Ogden 1985), the most buoyant being the small-seeded ones which are reported to be "buoyant until the waxy coat becomes wetted by turbulence" (Preest 1963). The long flotation period coupled with the large numbers of seed falling directly into water, make the potential water dispersal of Huon pine seeds enormous. This form of dispersal is limited to the floodline or directly to the edge of water courses. The Condominium Creek example shows that even with this good seed dispersal, expansion of this stand 400 m downstream appears to have taken at least 200 years and possibly 400 years or longer, based on stem diameter measurements and average diameter increments (Gibson 1986).

Many of the seedling sites on soil (table 3) were observed to be on "mossy mounds", which may be the more stable sections of the bank and consequently less prone to erosion due to flooding. The data on seedling substrates demonstrates that logs are not the major germination site, as they are reported to be in other habitats and for other species (Harman & Franklin 1989, Read & Hill 1983). It has been pointed out by Harman & Franklin (1989) that, even where logs do form the major germination sites, these sites are not necessarily suitable for establishment of mature trees, due to competition between trees and the inadequacy of the substrate for larger root penetration. This view contrasts with that of Read & Hill (1983), who suggested that, in regenerating forests, logs may provide "competition free" sites.

Playford and Detman (1979) have suggested from pollen data that Huon pine may have been much more widespread in the Tertiary. MacPhail (1979) and Colhoun & van de Geer (1987) have suggested that Huon pine survived the last glaciation in isolated refugia, and that the present distribution has expanded from these refugia. Macrofossil evidence does not support the view of widespread Huon pine distribution during the Tertiary (Wells & Hill 1989, Hill & MacPhail 1985, Hill 1990). Hill (1990) suggests that fossil pollen from the Tertiary may belong to a suite of Podocarpaceae species which pre-dated or were more abundant than Huon pine. Even if the past climate allowed an expanded distribution, range extensions, particularly uphill and away from rivers, would have taken extremely long periods of time. The origins of isolated high altitude sites such as at Lake Vera, Mt Read and Greystone Bluff have not, in my view, been satisfactorily explained, although green rosellas or their predecessors may have played an important role.

Conservation and Management

Huon pine has been singled out by the general community as an individual species worthy of specific conservation. In addition to the general conservation of its representative community types as outlined by Gibson (1986), this study has identified strategies based on its biology which may help to ensure its long-term survival. Since most effective dispersal appears to be down water channels, stands at the headwaters of catchments may represent stocks from which downstream regeneration may be possible but which would not be restocked if cleared. Thus, they represent key stands to be conserved. In addition, the stands on river flats and away from major stream flow are not likely to be easily regenerated from surrounding stands since lateral dispersal is extremely limited, and these, therefore, should be targeted for conservation. Some of these stands may have arisen from past river courses or flooding and, since many rivers are now controlled by upstream dams, flooding is less likely to provide an appropriate seed source in the future. The stands may represent distinct genetic subsets, due to their isolation from other stands, and so may be worthy of protection for this reason also. Riverbank integrity is important for the germination and establishment of seedlings, as most seedlings have been found on soil, sand and mossy mounds and most trees are found along river edges. Activities which degrade river banks will consequently reduce the survival of Huon pine. For example, continual deposition of material can smother young plants, and wave action which erodes the bank can undermine root systems and wash away seedlings. Vegetated buffer zones around Huon pine stands, and particularly along water courses, would also be beneficial since they will protect against fire and allow establishment of seedlings and saplings of Huon pine by maintaining a more constant moist environment.

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REFERENCES

Baker, H.G., 1989: Some aspects of the natural history of seed banks. *In* Leck, M.A., Parker, V.T. & Simpson R.C. (Eds): *ECOLOGY OF SOIL SEED BANKS.* Academic Press, New York and London: 9–21.

Ballardie, R.T. & Whelan, R.J., 1986: Masting, seed dispersal and seed predation in the Cycad *Macrozamia communis. Oecologia* 70: 100–105.

Berrigan, S.J., 1982: Research of seed scatter of King Billy Pine. Unpubl. report, Forestry Commission, Tasmania.

Brown, P., 1984: Food and feeding of the Green Rosella. *Tasmanian Bird Report* 13: 17–24.

Colhoun, E.A. & Van de Geer, G., 1987: Vegetation history and past climate before the maximum of the last glaciation at Crotty, Western Tasmania. *Pap. Proc. R. Soc. Tasm.* 121: 69–74.

Davies, J., 1983: *HUON PINE SURVEY. Div. Wildl. Tech. Rep.* 83/2. National Parks and Wildlife Service, Tasmania.

Francey, R.J., Barbetti, M. & Bird, T., *et al.*, 1984: *ISOTOPES IN TREE RINGS. Tech. Pap. 4.* CSIRO Australian Division of Atmospheric Research: 1–86.

Gibson, N., 1986: *HUON PINE CONSERVATION AND MANAGEMENT. Div. Wildl. Tech. Rep.* 86/3. National Parks and Wildlife Service, Tasmania.

Gibson, N., 1988: A description of the Huon Pine (*Lagarostrobos franklinii* (Hook. f.) C.J. Quinn.) forests of the Prince of Wales and King Billy Ranges. *Pap. Proc. R. Soc. Tasm.* 122(2): 127–133.

Harman, M.E. & Franklin, J.F., 1989: Tree seedlings on logs in Picea-Tsuga forests of Oregon and Washington. *Ecology* 70(1): 48–59.

Hickey, J.E., Blakesly, A.J. & Turner, B., 1982: Seedfall and germination of *Nothofagus cunninghamii* (Hook.) Oerst. *Eucryphia lucida* (Labill.) Baill. and *Atherosperma moschatum* Labill. Implications for regeneration practice. *Aust. For. Res.* 13: 21–28.

HILL, R.S., 1990: The fossil history of Tasmania's rainforest tree species. *Tasforests* 2(1): 5–12.

HILL, R.S. & MACPHAIL, M.K., 1985: A fossil flora from rafted plio-pleistocene mudstones at Regatta Point, Tasmania. *Aust. J. Bot.* 33: 497–517.

HOWARD, T.M., 1973: Studies in the ecology of *Nothofagus cunninghamii* Oerst. II. Phenology. *Aust. J. Bot.* 21: 79–92.

JANZEN, D.H., 1976: Why do bamboos wait so long to flower? *Ann. Rev. Ecol. Syst.* 7: 347–391.

JANZEN, D.H., 1983: Dispersal of seeds by vertebrate guts. *In* Futyama, D.J. & Slatkin, M. (Eds.): *COEVOLUTION.* Sinauer Associates, Sunderland, Mass.: 232–262.

LOUDA, S.M., 1989: Predation in the dynamics of seed regeneration. *In* Leck, M.A., Parker, V.T. & Simpson, R.L. (Eds.): *ECOLOGY OF SOIL SEED BANKS.* Academic Press, New York and London: 25–49.

MACPHAIL, M.K., 1979: Vegetation and climates in Southern Tasmania since the last glaciation. *Quaternary Research* 11: 306–341.

MILLINGTON, R.J., JONES, R., BROWN, D. & VERNON, B., 1979: *HUON PINE — ENDANGERED? Univ. Tasm. Environ. Stud. Occ. Pap.* 9.

NORTON, D.A., HERBERT, J.W. & BEVERIDGE, A.E., 1988: The ecology of *Dacrydium cupressinum*: a review. *N. Z. J. Bot.* 26: 37–62.

O'DOWD, D.J. & GILL, A.M., 1984: Predator satiation and site alteration following fire: mass reproduction of alpine ash (*Eucalyptus delegatensis*) in Southeastern Australia. *Ecology* 65(4): 1052–1066.

OGDEN, J., 1985: An introduction to plant demography with special reference to New Zealand trees. *N.Z. J. Bot.* 23: 751–772.

PEDLEY, J., BROWN, M.J. & JARMAN, S.J., 1980: *A SURVEY OF HUON PINE IN THE PIEMAN RIVER STATE RESERVE AND ENVIRONS. Wildl. Div. Tech. Rep. 80/2.* National Parks and Wildlife Service Tasmania.

PETERSON, M.J., 1990: *DISTRIBUTION AND CONSERVATION OF HUON PINE.* Forestry Commission, Tasmania.

PLAYFORD, G. & DETTMAN, M.E., 1979: Pollen of *Dacrydium franklinii* Hook. f. and comparable early Tertiary microfossils. *Pollen et Spores* 20: 513–534.

PREEST, D.S., 1963: A note on the dispersal characteristics of the seed of the New Zealand podocarps and beeches and their biological significance. *In* Gressit, L.S. (Ed.): *PACIFIC BASIN BIOGEOGRAPHY. 10th Pacific Science Congress, Honolulu, Hawaii, 1961.* Bishop Museum Press: 415–424.

QUINN, C.J., 1982: Taxonomy of *Dacrydium* Sol. ex Lamb. amend de Lamb. (Podocarpaceae). *Aust. J. Bot.* 30: 311–320.

READ, J. & HILL, R.S., 1983: Rainforest invasion onto Tasmanian old-fields. *Aust. J. Ecol.* 8: 149–161.

SHAPCOTT, A., 1991: Studies in the population biology and genetic variation of Huon pine (*Lagarostrobus franklinii*). *NRCP Tech. Rep. 4.* National Rainforest Conservation Program and Department of Parks, Wildlife and Heritage, Hobart, and Department of the Arts, Sport, the Environment and Territories, Canberra.

SILVERTOWN, J.W., 1980: The evolutionary ecology of mast seeding in trees. *Biol. J. Linnean. Soc.* 14: 235–250.

WARDLE, J.A., 1984: The New Zealand beeches, ecology utilisation and management. New Zealand Forest Service.

WELLS, P.M. & HILL, R.S., 1989: Fossil imbricate-leaved Podocarpaceae from Tertiary sediments in Tasmania. *Aust. Syst. Bot.* 2: 387–423.

(accepted 3 May 1991)

DISTRIBUTION AND HABITAT OF *HELICARION RUBICUNDUS* (PULMONATA: HELICARIONIDAE), A RARE LAND SNAIL

by Robert J. Taylor

(with one text-figure)

TAYLOR, R.J. 1991 (20:xii): Distribution and habitat of *Helicarion rubicundus* (Pulmonata: Helicarionidae), a rare land snail. *Pap. Proc. R. Soc. Tasm.* 125: 27–28. ISSN 0080-4703. Forest Practices Unit, Forestry Commission, 30 Patrick Street, Hobart, Tasmania, Australia 7000.

Distribution records and details of habitat are provided for *Helicarion rubicundus*, a land snail. This species was previously known only from one location. It was found to occur through much of the wet forest on Forestier Peninsula but to be rare within suitable habitat on Tasman Peninsula.

Key Words: land snail, Tasmania, pulmonate.

INTRODUCTION

In 1976, Dartnall and Kershaw (1976) described a new species of *Helicarion* in Tasmania, *H. rubicundus*. The specific name was chosen to draw attention to the colour of the animal, which is burgundy. The species has been referred to by the common name of the burgundy snail.

Helicarion rubicundus can be readily distinguished from its congener, *H. cuvieri*, by body colouration (*H. rubicundus* – burgundy, sometimes with a green tinge; *H. cuvieri* – grey, greyish buff or white) and caudal mucus (*H. rubicundus* – red; *H. cuvieri* – yellow). The genus *Helicarion* is distinguished by the small, thin, transparent shell, which is convex to flat with a greatly enlarged body whorl. The body can only be partly withdrawn into the shell. Accessory lobes of the mantle partly cover the shell. The foot is posteriorly truncate.

The specimens on which the description of *H. rubicundus* were based came from a gully just north of Eaglehawk Neck on Forestier Peninsula and were collected in 1971. This is the only locality from which they were known. They had not been found in similar habitat on Tasman Peninsula despite intensive searches at several localities (K. Bonham, pers. comm.). The present study was undertaken to try to locate further populations of *H. rubicundus* and to gain an understanding of its habitat requirements.

METHODS

Searches for *H. rubicundus* were undertaken on Forestier and Tasman Peninsulas on 8, 18 and 19 July and 5 and 6 December 1989. Twenty-four sites on Forestier Peninsula and six sites on Tasman Peninsula were examined. At each site, searching was undertaken either until *H. rubicundus* was found or for a period ranging between thirty and ninety minutes.

RESULTS

Distribution

Sites searched and locations where *H. rubicundus* were found are shown in figure 1. The species occurs at numerous locations on Forestier Peninsula but was found at only one site on Tasman Peninsula.

Habitat Preferences

The distribution of wet and dry sclerophyll forest in the study area is shown in figure 1. No specimens were found in dry sclerophyll forest. On Forestier Peninsula, *H. rubicundus* was found in 15 out of the 20 sites in wet forest that were searched, but in only one of the six wet forest sites on Tasman Peninsula. No factors associated with their absence from wet sites could be recognised. They were found close to creek lines, on slopes above creeks and on flatter ridge tops. Vegetation of these sites was typical of wet forests. Dominant eucalypts present were *Eucalyptus obliqua*, *E. regnans* and *E. globulus*. Common understorey species included *Pomaderris apetala*, *Bedfordia salicina*, *Notelaea ligustrina*, *Blechnum wattsii*, *Dicksonia antarctica*, *Atherosperma moschatum*, *Melaleuca squarrosa*, *Gahnia grandis*, *Olearia argophylla*, *Coprosma quadrifida*, *Zieria arborescens*, *Lepidosperma elatius*, *Tasmannia lanceolata*, *Leptospermum lanigerum* and *Acacia melanoxylon*. The undergrowth was mostly open, with a well-developed leaf litter. However, specimens were also collected from areas where *Gahnia* clumps were frequent. Snails were found in 20-year-old regeneration resulting from clearfelling, previously cut-over forest and old growth.

Sheltering Sites

Helicarion rubicundus is normally inactive during the day, and hence situations in which they occur represent sheltering sites. Individuals were found under rocks, under bark on fallen trees, in litter accumulated at the base of trees or sedges and in curled pieces of thin bark. By far the most rewarding site was curled bark. The snails appeared to prefer clean

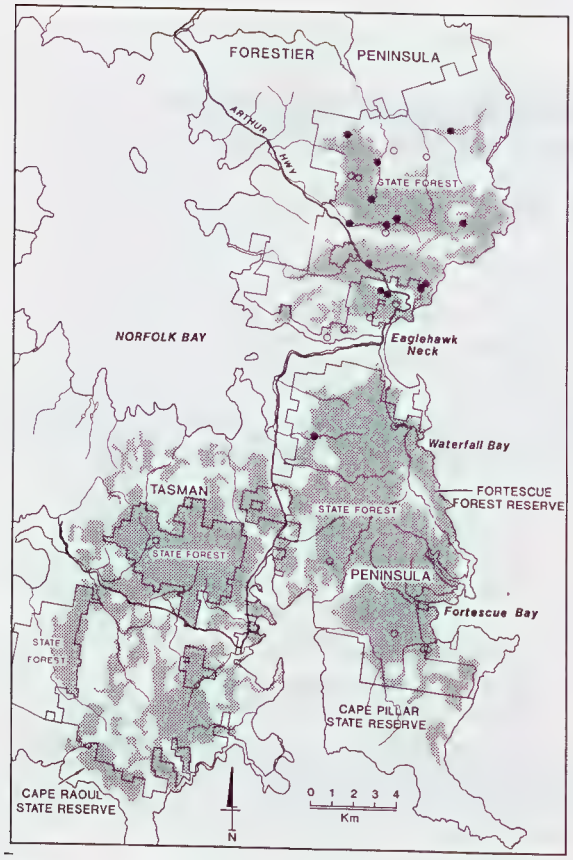

FIG. 1 — Distribution of suitable habitat for Helicarion rubicundus. ○ = *wet sclerophyll forest,* • = *locations where* H. rubicundus *was found,* o = *locations where searches were unsuccessful.*

pieces of bark rather than old, dirty, decaying pieces. Curled eucalypt bark is a typical shelter for *Helicarion, Cystopelta* and some other small species in many parts of Tasmania (R. Kershaw, pers. comm.).

DISCUSSION

Helicarion rubicundus shows a distinct preference for wet forest. It was found to be widespread within these forests on Forestier Peninsula. However, the species was not found at all such sites. Whether it would have been found with further searching is not known, but the species did appear to differ in abundance between localities in suitable habitats. Further work would be needed to quantify and explain these differences. One site where the species appeared to be plentiful was in 20-year-old silvicultural regrowth. *H. rubicundus* was also noted in other sites with young forest and in areas where the presence of stumps indicated past selective logging.

Helicarion rubicundus seems to have suffered a decline in its type locality. An intensive search here failed to locate any specimens. A single individual was found further up the gully. R. Kershaw (pers. comm.) has noted that there has been a considerable increase in shrub cover at the type locality since the species was first discovered there.

On Tasman Peninsula, *H. rubicundus* seems to be much rarer and/or more restricted than on Forestier Peninsula. Other searches at several locations on Tasman Peninsula have also failed to reveal any *H. rubicundus* (K. Bonham, pers. comm.) .

Helicarion cuvieri was found in most of the sites where *H. rubicundus* was located. It also occurred at other sites where no *H. rubicundus* was found, including some locations in dry sclerophyll forest. *H. cuvieri* thus appears to tolerate a wider range of environments than does *H. rubicundus.* There was no obvious inverse relationship between the apparent densities of the two species which might have been expected if competition between them was occurring. At the site with silvicultural regrowth, both species appeared to be abundant.

This study has found *H. rubicundus* to be much more widespread than the single locality from which it was previously known. Its overall range is still quite restricted and it ranks as one of the rarest of the Tasmanian terrestrial snails on a statewide basis (Smith & Kershaw 1981). It is certainly more restricted than *Anoglypta launcestonensis* (Kershaw 1988), a species whose conservation status has received much attention. Most of the range of *H. rubicundus* is encompassed by State forest. Populations appear not to have been disadvantaged by past logging operations. However, further monitoring of the effects of logging is warranted, given the rarity of the species. It is likely that a wide section of forest along the eastern coastline of Forestier Peninsula will remain unlogged (see maps in Williams *et al.* 1990 and Taylor 1990). It, therefore, appears likely that the species will remain secure for the foreseeable future.

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Ron Kershaw verified my identification of *Helicarion rubicundus.* I would like to thank Ric Dowling for accommodation and his interest in the work. Bill Brown prepared figure 1. Kevin Bonham and Bill Brown helped with field work. R.C. Kershaw, B.J. Smith and M. Brown provided comments on a previous draft. The study was funded by the Forestry Commission.

REFERENCES

DARTNALL, A.J. & KERSHAW, R.C., 1976: Description of a new species of *Helicarion* (Stylommatophora: Helicarionidae) in Tasmania. *Rec. Q. Vict. Mus.* 62: 1–18.

KERSHAW, R.C., 1988: A study of the Caryodidae (Pulmonata) Part 1. *Anoglypta launcestonensis* (Reeve 1953). *Rec. Q. Vict. Mus.* 93: 1–24.

SMITH, B.J. & KERSHAW, R.C., 1981: *TASMANIAN LAND AND FRESHWATER MOLLUSCS. Fauna of Tasmania Handbook* 5. University of Tasmania, Hobart.

TAYLOR, R.J., 1990: *FAUNA MANUAL.* Forestry Commission, Hobart.

WILLIAMS, K., DUNCAN, F. & TAYLOR, R., 1990: Biological conservation in Tasmania's production forests. *Tasforests* 2: 73–78.

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THE FAUNAL ASSEMBLAGE IN FRESHWATER CRAYFISH BURROWS IN SEDGELAND AND FOREST AT LIGHTNING PLAINS, WESTERN TASMANIA

by Pierre Horwitz and Brenton Knott

(with one table and one text-figure)

HORWITZ, P. & KNOTT, B., 1991 (20:xii): The faunal assemblage in freshwater crayfish burrows in sedgeland and forest at Lightning Plains, western Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 29–32. ISSN 0080–4703. Department of Geography and Environmental Studies, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001; and Department of Zoology, University of Western Australia, Nedlands, WA, Australia 6009.

The faunal assemblage of crayfish burrows was examined intensively at Lightning Plains in western Tasmania, in sedgeland and adjacent forest, to determine variations in species occurrences and abundances both within one habitat type and between two habitats. Species–sample curves showed that over 90% of the species found in ten samples could be collected by taking only five. Despite the fact that the host crayfish species was the same, each habitat was found to display a characteristic assemblage. Variations between the assemblages are attributed to differences in soil conditions, vegetation structure and watertable behaviour.

Key Words: Western Tasmania, invertebrates, crayfish, burrows, pholeteros.

INTRODUCTION

Previous investigations of the freshwater fauna in crayfish burrows of western Tasmania (Lake & Newcombe 1975, Suter & Richardson 1977, Horwitz 1989) or elsewhere in southeastern Australia (Horwitz *et al.* 1985, Boulton 1989) have used "snapshot" sampling events and substantial information has been gained from this approach. The "pholeteros" *(sensu* Lake 1977) is now known to include diverse crustacean and oligochaete faunas, as well as nematodes, dipteran and other insect larvae, with up to 20 species in any one burrow system. However, snapshot sampling events can only record species occurrences in the particular time and season available for sampling, under the climatic conditions on the day. Also, variations of habitats potentially capable of harbouring rare species have not, so far, been analysed systematically and quantitatively. This paper aims to correct this omission, at least partially, by examining the variation in the occurrence of species in the pholeteros from burrow to burrow within a site on a single occasion. Another aim is to determine whether the fauna varies between sites with different microhabitats. In doing so, it was hoped to estimate the number of samples required to collect a major proportion of the species of pholeteros in an identifiable habitat type at any one time.

METHODS

The examination of pholeteros was conducted at Lightning Plains, a flat area in the headwaters of the Jane River, just south of Frenchmans Cap in western Tasmania, lying at an altitude of 360–400 m. Despite their simple topography, the plains exhibit a heterogeneous set of geological, pedological and hydrological conditions, and this characteristic of Lightning Plains gave us an opportunity to examine the variation of pholeteros in different habitats. Within a relatively small distance (200–300 m), two distinct crayfish burrow habitats occurred: on the western side of a low dolomite ridge was a buttongrass plain (sedgeland) and immediately east of the ridge was mixed forest.

The sedgeland site was dominated by grasses, herbs and shrubs, including *Gymnoschoenus sphaerocephalus* (R.Br.) Hook.f. (buttongrass), *Restio* spp., *Xyris* sp., *Leptocarpus* sp., *Melaleuca squarrosa* Donn ex Smith, *Callistemon* sp. and *Leptospermum* sp., on soils composed of shallow peats (50–150 mm) overlying silty sand on quartzitic gravel. The "Forest" site occurred on a claypan (impeded drainage) and burrows were constructed in grey-brown, silty loamy clay soils, where the vegetation was dominated by a *Eucalyptus nitida* Hook.f. overstorey with *Leptospermum* sp. and *Nothofagus cunninghamii* (Hook.) Oersted in a lower stratum; *Gahnia grandis* (Labill.) S.T.Blake and *Blechnum nudum* (Labill.) Mett. ex Luerss were the dominant components of the ground stratum. The water in the burrows at both sites had pH values of between 3.8 and 5.8.

All fieldwork was undertaken in late January 1989, when helicopter transport was available; it was not possible to resample in this remote locality. The techniques involved to collect, preserve and analyse samples were the same for the two sites.

The freshwater crayfish *Parastacoides tasmanicus inermis* (Clark) occurred at both sites. At the forest site a further two species were located, *Astacopsis franklinii* (Gray) and *Engaeus cisternarius* Suter, but by far the most abundant species was *P. t. inermis*. In sampling the pholeteros, burrows with similar-looking surface openings were selected in order to ensure that a maximum number of *P. t. inermis* burrows were analysed (rather than those of the other species). Thus, at both sites the structure of burrows sampled was similar, with usually two or three entrances converging to form one descending tunnel to 0.35–0.60 m depth, where the burrow terminated in a slightly enlarged chamber.

In each burrow the watertable was carefully exposed by removing the chimney of soil thrown up by the crayfish and the surface portions of the soil around the burrow. All water was completely removed from the burrow by inserting a siphon (10 mm internal diameter) and sucking it out; the water (containing the pholeteros) was then passed through a sieve (0.05 mm mesh-pore size). Whilst volumes were not measured in the field, most samples represented at least one litre, and there were no gross differences between the volumes

of burrows at each site. The sieved fraction remaining was preserved in 5–10% formalin in a plastic bag. The collecting equipment was thoroughly cleaned in filtered water between each sample to prevent contamination of subsequent samples.

Ten samples were taken from each site, with each sample representing a separate burrow system. Crayfish (either juveniles or adults) were found in all but three of the burrows sampled (two from sedgeland and one from forest); the crayfish were identified *in situ* and generally not collected.

In the laboratory, samples were washed through sieves of mesh-pore sizes 1 mm, 0.5 mm and 0.25 mm. (Animals capable of passing through a pore size of 0.25 mm were therefore not likely to have been detected.) Washed samples were sorted under a low-power dissecting microscope.

Collected taxa were identified to species level where possible, and placed into one of three groups:
(1) terrestrial species which are known to occur in leaf litter or the soil; these were assumed to be fall-ins;
(2) those species which are known to be symbiotic or commensal on freshwater crayfish (including temnocephalan flatworms and entocytherid ostracods); and
(3) "true" members of the pholeteros.

Only data from this third group were analysed further. Each species per sample was assigned an abundance value: absent, rare (one individual only), few (2–10 individuals) and common (more than 10 individuals). Species–sample curves were constructed for each site using presence–absence data. The data were classified using the polythetic divisive computer programme TWINSPAN (Hill 1979), taking abundance classes as cut levels.

RESULTS

Species of invertebrates which were deemed to be terrestrial included five species of terrestrial mites, one species of Opilionidae, paronellid collembolans, earthworms, an oniscid isopod (*Styloniscus* sp.) and one adult curculionid coleopteran. These species were excluded from the analysis presented below.

Twenty-seven taxa were recognised as being true components of the pholeteros. Of these, 24 were found in burrows in the sedgeland area, with between 8 and 15 species in individual samples. For the forest site, 19 species were identified, with between 5 and 12 species from each burrow. Species–sample curves (cumulative frequency plots — fig. 1) show that over 90% of the species in sedgeland burrows are found in the first five samples and 100% of all species were found in the first five samples in forest burrows.

The species found in this survey are given in table 1, showing two TWINSPAN groups; the level of division used was the first division, justified by the small number of samples and species. The twenty samples were split into one group of eight, comprising only samples from forest burrows, and one group of twelve. In the latter group, both of the forest burrow samples (numbers 14 and 16, table 1) were borderline in the division and were also allied to the forest group. Therefore, the division clearly separated forest burrows from sedgeland burrows on the basis of the faunistic abundance data. Important indicator taxa for this division included the oligochaete species 4 and 5, chironomid (Orthocladiinae) larvae and the cyclopoid copepods *Acanthocyclops* sp. nov. and *Diacyclops cryonastes* Morton. The cyclopoid species are important in terms of their abundances, with *Acanthocyclops* sp. nov. more abundant

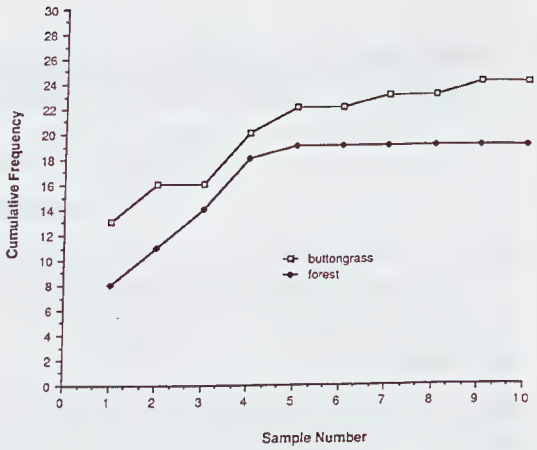

FIG. 1 — Typical cumulative frequency plots of the number of species found in each sample at each site (presented in the order in which they were collected).

than *D. cryonastes* in sedgeland burrows, and vice versa for forest burrows.

Sixteen taxa were found in samples at both sites. Of these, eight taxa might be regarded as commonly occurring at both sites: the nematodes, the ostracod *Candona* nr. *tecta*, the two cyclopoid copepods, the harpacticoid copepod *Canthocamptus* sp., amphipod *Neonipharg us* nr. *tasmanicus*, the janirid isopod *?Heterias* sp. and the oligochaete *Phreodrilus proboscidea* Brinkhurst and Fulton.

Eleven species were restricted to one or the other site: eight species were found only in sedgeland burrows while three were restricted to burrows in forest.

DISCUSSION

The composition of the pholeteros at Lightning Plains is essentially similar to that which one would expect to find elsewhere in southwestern Tasmania (see Horwitz 1989), although the absence of syncarid and phreatoicid crustaceans is intriguing, at least from a zoogeographical point of view. The finds of cladocerans, gastropods and an odonatan are new records for the faunal assemblage of crayfish burrows.

The species–samples curves show that over 90% of the fauna available in ten samples could be collected by taking only five, and 1 or 2 samples will collect at least 50% of the faunal assemblage. The sampling technique used in this survey sampled each burrow completely by removing all burrow water. At other sites it may not be possible to completely empty (or sieve) all the burrow water and this could well result in an inability to collect rarer species; under these conditions larger numbers of samples may be needed to obtain representativeness.

The higher species richness in sedgeland burrows compared to that in forest burrows may be due to an interaction between two related characteristics of sedgeland areas, namely organic rich soil (peat) and a high watertable. The presence of peat could in theory provide proportionately larger amounts of nutrient (in the form of organic soil particles and associated microbial flora), compared to the relatively inert mineral soils in the forest. The presence of a watertable

TABLE 1

TWINSPAN results showing the species found in each sample (where samples are numbered from 1–10 for buttongrass, and 11–20 for forest), the division recognised by TWINSPAN at the first level, and the species divisions at the first level. Abundance values for each species present in each sample (1, 2 or 3) are explained in the text.

	Sample number	4	5	6	9	10	3	7	1	2	8	14	16	13	17	20	11	19	12	15	18	Species Divisions (1st Level)
Class/Order	**Species**																					
OLIGOCHAETA	Oligochaete sp. 3									1	1											0
AMPHIPODA	*Neonipharqus* nr. *spenceri*							2														0
DIPTERA	Tabanidae (larvae)				1				1		1	1										0
CLADOCERA	*Bosmina* sp.	1				2			1			2										0
GASTROPODA	*Glacidorbis* sp.	2	3	3		2		2														0
OSTRACODA	Cyprididae sp. nov.		3	3	1	3		3			1											0
DIPTERA	Orthocladiinae (larvae)	2	2	1	2	1				2	2											0
ODONATA	*Synthemis macrostigma orientalis*	1																				0
DIPTERA	Ceratopogonidae (larvae)		2		1																	0
DIPTERA	Culicini (larvae)	2	2	1	1	1			1		1									3		0
DIPTERA	Orthocladiinae (pupae)		2	2						1												0
COLEOPTERA	Helodidae (larvae)							1	1	1		1							1			0
COPEPODA	*Acanthocyclops* sp. nov.	3	3	3	2	3	3	3	3	2	3	2		2	2		2	2	2			1
NEMATODA	Nematoda sp. or spp.	2	2	3	3	3	3	3	2	3	2	2	1	2	2	2		2	3		2	1
OLIGOCHAETA	Oligochaete sp. 2		1	1	1	1	1	1	1	1	1			1		1	1		1			1
OSTRACODA	*Candona* nr. *tecta*	3	3	3	2	3	3	3	3	3	3	3	2	3			3	3	3	3		1
COPEPODA	*Canthocamptus* sp.	1	2	3	1	1	2	2	1	1		2		2	1	1	1	1				1
AMPHIPODA	*Neonipharqus* nr. *tasmanicus*			3	2	3	3	3	3	2	3	3	2	2		2	1	3	3	3		1
ISOPODA	? *Heterias* sp.	1		3	3	3	3	3	3	2	3	3	2	3			3	3	3	3		1
COPEPODA	*Diacyclops cryonastes*	2	3		1	2	2	2	3	2	3	2	2	3	3	1	3	3	3	3	3	1
OLIGOCHAETA	*Phreodrilus probiscidea*			1					1	1		1			1	1	1		1	2		1
DIPTERA	Limoniinae (larvae)				1														2		1	1
DIPTERA	Unidentified larvae sp. 3											1									1	1
OLIGOCHAETA	Oligochaete sp. 4	1												1	1				1	1	1	1
OLIGOCHAETA	Oligochaete sp. 5	1			1						1			1	1	1				1	1	1
DIPTERA	Unidentified larvae sp. 1												1	1								1
DIPTERA	Unidentified larvae sp. 2													2								1
	TWINSPAN Division (1st Level)	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	
	TOTAL NUMBER OF SPECIES	13	12	13	15	13	8	12	13	13	13	12	5	12	8	7	10	8	10	8	6	

in the peat makes the peat available to the pholeteros by providing a water continuum between the space in the burrow and the spaces in the soil. (During the sampling of burrows, after water was extracted from burrows in sedgeland, they refilled relatively quickly, whilst those in the forest refilled either very slowly or not at all.) Sedgeland burrows are therefore part of a much larger reservoir of water which occupies the interstitial spaces in the peats and below.

Furthermore, watertable fluctuations in sedgeland areas are likely to be greater in amplitude because the more exposed conditions lead to greater evapo-transpiration in summer, amongst other things. At the end of summer, when the site was visited, the numerous pools on the surface in the sedgeland were all dry. The presence of surface pools may well explain the better representation of chironomids, culicids and ceratopogonids in sedgeland; these insects deposit eggs in the pools, and then larvae and pupae are forced to over-summer in burrows as they follow the watertable. The ability of crayfish burrows to carry a temporary freshwater fauna through summer has been noted before (for instance Williams *et al.* 1974). This may be another reason for higher species richness in sedgeland burrows and the larger number of samples required to collect all identified species, compared to the forest, where no surface depressions or pools were apparent.

Finally, it should be remembered that species symbiotic or parasitic on crayfish have been removed from the analysis. Further discriminatory data may be available to characterise either microhabitat variation within one site or variation between habitats by examining this collection of species. For instance, the ectocommensal temnocephalan species *Temnocephala ?cita* was found on crayfish from sedgeland burrows whilst *T. ?pygmaea* was found on the same crayfish host from forest burrows.

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REFERENCES

Boulton, A.J., 1989: Over-summering refuges of aquatic macroinvertebrates in two intermittent streams in central Victoria. *Trans. R. Soc. SA* 113: 23–34.

Hill, M.O., 1979: *TWINSPAN — A FORTRAN PROGRAM FOR ARRANGING MULTIVARIATE DATA IN A TWO-WAY TABLE BY CLASSIFICATION OF INDIVIDUALS AND ATTRIBUTES.* Cornell University, Ithaca.

Horwitz, P., 1989: The faunal assemblage (or pholeteros) of some freshwater crayfish burrows in southwest Tasmania. *Bull. Aust. Soc. Limnol.* 12: 29–36.

Horwitz, P., Richardson, A.M.M. & Boulton, A.J., 1985: The burrow habitat of two sympatric species of land crayfish, *Engaeus urostrictus* and *E. tuberculatus* (Decapoda: Parastacidae). *Vict. Nat.* 102: 188–197.

Lake, P.S., 1977: Pholeteros — the faunal assemblage found in crayfish burrows. *Aust. Soc. Limnol. Newsl.* 15: 57–60.

Lake, P.S. & Newcombe, K.J., 1975: Observations on the ecology of the crayfish *Parastacoides tasmanicus* (Decapoda; Parastacidae) from south-western Tasmania. *Aust. Zool.* 18: 197–214.

Suter, P. & Richardson, A.M.M., 1977: The biology of two species of *Engaeus* (Decapoda: Parastacidae) in Tasmania III. Habitat, food, associated fauna and distribution. *Aust. J. Mar. Freshw. Res.* 28: 95–103.

Williams, D.D., Williams, N.E. & Hynes, H.B.N., 1974: Observations on the life history and burrow construction of the crayfish *Cambarus fodiens* (Cottle) in a temporary stream in southern Ontario. *Can. J. Zool.* 52: 365–370.

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PREDATORS ON MARINE FISH FARMS IN TASMANIA

by David Pemberton, Nigel Brothers and Geof Copson

(with two tables)

PEMBERTON, D., BROTHERS, N. & COPSON, G., 1991 (20:xii): Predators on marine fish farms in Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 33–35. ISSN 0080–4703. Ocean Sciences Center, Memorial University of Newfoundland, St Johns, Newfoundland, Canada A1C 5S7 (DP); Department of Parks, Wildlife and Heritage, 134 Macquarie Street, Hobart, Tasmania, Australia 7000.

Marine aquaculture of the salmonids atlantic salmon (*Salmo salar*) and rainbow trout (*Salmo gairdneri*) is a rapidly growing industry in Tasmania. There is considerable damage to the fish on these farms by avian and mammalian predators. The mode by which these predators attack the fish on the farms allows for practical methods to reduce the loss of fish. Physically excluding predators from the fish is ultimately the only way to prevent this loss entirely. A total of six predators that interact with the farms are described and the necessity for the protection methods to be incorporated into the design of the farms prior to farm development is emphasised.

Key Words: aquaculture, salmonids, seal, silver gull, cormorant, water rat, sea eagle, management.

INTRODUCTION

Marine aquaculture of the salmonids atlantic salmon (*Salmo salar*) and rainbow trout (*Salmo gairdneri*) is a rapidly growing industry in Tasmania, with 19 operational farms in 1990. These farms are located in southeastern Tasmania (16 farms) and in Macquarie Harbour (three farms) in the southwest of the state. The farms vary in size, producing from 100 to 250 tonnes of fish per year. The fish are farmed in pens, termed "polar circles", that are constructed with polypipe. They vary from 20 to 60 m in diameter and have a net hanging to approximately 5 m deep. These pens are stocked with 10 to 15 kg/m^3 of fish which, depending on the time of year, are between 0.05 and 0.4 m in length. These large concentrations of fish attract many predators.

Finfish aquaculture also occurs in Western Australia and South Australia, and will probably spread to others areas of the country. Neither in Tasmania nor overseas (Ross 1988) has the problem of predators been taken into account prior to aquaculture establishment. Consequently, the impacts of the predators on the fish farms are often difficult to control because of inappropriate siting of the farms, design faults and high unplanned costs.

It is the aim of this paper to identify the avian and mammalian predators that come into conflict with fish farms in Tasmania and to discuss practical ways to reduce their impact.

METHODS

A total of seven fish farms in southeastern Tasmania were surveyed to establish what predators were causing problems and the nature of these problems. Farmers were interviewed and direct observations were made of predators of the farms from 1987 to 1990. The species of predators involved in the interaction, how they entered the nets and any action taken by the farmers to prevent entry were recorded. Because farmers tend to blame certain predators for damage to fish when these predators were not actually observed causing the damage, it was necessary for the authors to verify all information obtained from farmers. Only those records where the predators were seen in the fish pens catching fish or attempting to, or where the damage to the fish was characteristic of a certain predator, were accepted. Predation by seals and cormorants could be identified by the damage to the fish. Those attacked by seals have parallel scrapes and punctate holes caused by the seals canines. Cormorants jab and grab at fish with their beaks, resulting in either small single punctate wounds or single striations.

The nets that hang from the pens to contain the fish are referred to as containment nets, whilst nets hung outside the containment net to prevent attack by predators are referred to as protection nets.

OBSERVATION ON PREDATION

A total of six species of predators were found to interact to some degree with fish farms. These included Australian fur seals (*Arctocephalus pusillus doriferus*), silver gulls (*Larus novaehollandiae*), water rats (*Hydromys chrysogaster*), two cormorant species (*Phalacrocorax carbo, P. fuscescens*) and white-bellied sea eagles (*Haliaeetus leucogaster*).

The degree of interaction varied. All seven farms incurred problems with seals and silver gulls, four with water rats, three with sea eagles and two with cormorants. The great cormorant (*P. carbo*) was a confirmed predator on fish farms, and there were occasional reports by farmers of a smaller species of cormorant that attacked fish. This was probably the black-faced cormorant (*P. fuscescens*) which is common in these waters.

Seals, cormorants and white-bellied sea eagles were the only predators observed capturing fish out of the pens. Though silver gulls and water rats have the ability to capture fish, this was never observed. Silver gulls fed on the fish food as it was distributed by automatic feeders over the pens. In addition, while waiting for the periodic release of the feed they defecated in the pens, thereby producing a hygiene problem.

Seals gained access to the fish by penetrating the holding net. This resulted in holes varying in size from 0.05 to 3 m. Many seal attacks not only damaged fish but also resulted in the release of fish. Gulls, water rats, cormorants and sea eagles all entered the pen from above when the fish were exposed (table 1). Though water rats could chew through the nets and use existing holes, this was never recorded. Sea eagles were observed perching on the perimeter of the 20 m

TABLE 1
Characteristics of predators on seven fish farms

Predator	Orientation of entry into net		Maximum prey size* (cm)	Foraging technique
	Side	Surface		
Seal				
Arctocephalus pusillus doriferus	x	–	80	Pursuit diving
Silver gull				
Larus novaehollandiae	–	x	10	Surface seize and dipping
Water rat				
Hydromys chrysogaster	?	x	36	Pursuit diving
Great cormorant				
Phalacrocorax carbo	x†	x	40	Pursuit diving
Black-faced cormorant				
P. fuscescens	x†	x	11	Pursuit diving
Sea eagle				
Haliaeetus leucogaster	–	x	40	Surface plunging

* Data sources: seals (pers. obs.), water rats (Woollard *et al.* 1978, Watts & Aslin 1981), silver gulls (pers. obs.), cormorants (Miller 1979, Lalas 1983), sea eagles (N. Mooney, pers. comm.)
† Cormorants do seize fish through the net but do not penetrate into the pen.

TABLE 2
Number of fish farms in Tasmania that used various methods to reduce the impact of predators

Predator*	Shooting	Capture and removal	Protection nets	Emetics	Scare crackers	No action
Seals	7	–	6	3	4	–
Gulls	–	–	7	–	2	–
Water rats	1	2	–	–	–	1
Cormorants	2	–	–	–	–	–
Sea eagles	–	–	–	–	–	3

* Species names as in table 1.

diameter pens but were never actually seen to take fish, although they made frequent attempts. The reports of sea eagles catching fish were only in association with the larger 60 m diameter polar circle.

MINIMISATION OF PREDATION

This study identified six species of birds and mammals that prey on the fish in fish farms and showed that all marine fish farms are vulnerable to predation by these animals.

The farms surveyed all occur in the marine environment in waters between 20 and 30 m deep. They are sited in sheltered bays within 5 km of the open ocean. The predators described either live in these bays (water rats) or forage daily in these areas (seals, silver gulls, sea eagles and cormorants). These predators also have a foraging strategy, dietary preference and prey handling capacity which allows them to exploit farm fish (table 1). The way in which they exploit it varies and, in response, so does the protection method recommended. Protection methods used for the various predators are shown in table 2.

Seals charge the net (observed on six occasions), ram into it, grab at the fish and tear holes in the net. They are the only predator that actually damages the subsurface net to any great extent and, hence, the protection measures used are fundamentally different from those implemented for the other predators. Large sharks were recorded twice as the cause of large (1.5 m) tears in the containment nets. One of these attacks was by a thresher shark *(Alopias vulpinus).*

The strength and weight of the seals, and the speed at which they attacked pens meant that the protection system had to be extremely robust. Polyethylene protection nets, with strands 4 mm in diameter, stop seals, but the preferred option of wire netting (Boral Cyclone, pig mesh) is probably more effective (Pemberton & Shaughnessy, pers. comm.). Two deterrents, explosive seal crackers and emetics, were used by some farmers to prevent or reduce seal attacks (table 2). The seal crackers are waterproof explosives that are detonated in the vicinity of the individual seals to scare them into leaving the farm area. The emetics are deployed in baits, in an attempt to induce a conditioned food aversion in the seals to salmon and trout. Both these methods are effective in reducing the rate of attack but do not

prevent every attack (Pemberton & Shaughnessy, pers. comm.).

As silver gulls, cormorants and sea eagles forage by plunging into the pens from above, they were easily deterred by placing netting over the pens. Some farmers strung lengths of monofilament across the pens to prevent gulls from landing on the water. This proved to be futile and netting is effective only if it is strung over the top of the cage without any gaps. Gaps in the netting are soon exploited by both silver gulls and cormorants. Bird fright crackers which explode in the air were used by two farms as a trial in an attempt to frighten gulls, but this proved unsuccessful as the birds would return within hours. Cormorants also attacked the caged fish under the water through the containment nets. This form of attack is prevented by the outer protection nets described above, deployed to exclude the seals from the pens.

A more lateral approach was taken with water rats which, by virtue of their small size and agility, are far more difficult to prevent from entering the pens. The option of systematically removing water rats from the farms and relocating them in suitable habitats was discarded because it is likely that this would only be a temporary solution, as dispersal of water rats into the resource-rich area of the fish farm is likely to take place. In addition, removing animals to another area merely places pressure on the receiving population of water rats. Instead, the aggressive territoriality of water rats and their use of distinct feeding platforms was exploited (Watts & Aslin 1981). The farmers now place dead salmonid fish at set feeding sites. The rationale of this method is to supplement the diet of the resident water rats to reduce their impact on the penned fish, residents who, by maintaining their territorial boundaries, prevent the immigration of additional individuals from adjacent areas. There has not been any quantitative assessment of the efficacy of this method, but the farmers have observed water rats taking proffered fish and are satisfied that their impact on the fish mortalities has decreased.

Both the common dolphin (*Delphinus delphis*) and bottlenose dolphins (*Tursiops truncatus*) have been observed around and within the lease area of the fish farms. They have never attacked the fish in the pens and do not appear to cause the fish any disturbance. Therefore they are not considered to be a problem. Similarly, when a fish farm suffered damage to a pen caused by a southern right whale (*Eubalaena glacialis*), it was apparent that the damage was the result of the whale colliding with the pen, not of the animal attacking the penned fish.

All the predators described here, except the great cormorant, are wholly or partly protected under the *Tasmanian National Parks and Wildlife Act* 1970, and therefore shooting or capture can only be done under permit. Shooting as a method of control is costly and ineffective. Despite the wide use of 24-hour armed guards on the farms, deploying both crackers and shooting (table 2), the predators persist in feeding in the pens. There was only a 44% success rate at scaring seals away from the pens by shooting at them, and less than 10% of the attacking animals were shot (Pemberton & Shaughnessy, submitted).

The only practical way to reduce the impact of the predators on the fish farms is to physically exclude them. The farmers have to assess the losses caused by the predators against the cost and maintenance of exclusion methods. As a result, most farmers deploy physical exclusion nets for both volant and underwater predators (table 2). The geographical position of the farms in relation to the predators should also be taken into account when planning aquaculture development. The two farms that suffer the most damage from seals in Tasmania are located closest to seal haulout sites (Pemberton & Shaughnessy, submitted). A similar situation would probably occur with farms close to breeding sites of colonial breeding birds such as cormorants and gulls.

As the fish farming industry develops, so will the design of the fish cages. Changes in design may open new avenues for the predators to exploit. For example, there is a plan to increase the size and structure of pens, which will make the fish more vulnerable to sea eagles, since these require space in which to plunge, feed and take off again. To date, there have been no reported problems with white-faced herons (*Ardea novaehollandiae*), kelp gulls (*Larus dominicanus*) or dominican gulls (*L. pacificus*), which may be, in part, the result of cage design. Any change in cage design must take into account the method by which predators forage.

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REFERENCES

Lalas, C., 1983: Feeding ecology of New Zealand marine shags. Unpubl. PhD thesis, University of Otago, New Zealand.

Miller, B., 1979: Ecology of the Little Black Cormorant, *Phalacrocorax sulcirostris* and Little Pied Cormorant, *P. melanoleucos*, in inland New South Wales: food and feeding habits. *Aust. Wildl. Res.* 6: 79–95.

Pemberton, D., 1989: The interaction between seals and fish farms in Tasmania. Unpubl. rep. Tasmanian Department of Lands, Parks and Wildlife.

Ross, A., 1988: Controlling nature's predators on fish farms. Report for the Marine Conservation Society, Ross-on-Wye, England.

Watts, C.H.S. & Aslin, H.J., 1981: *THE RODENTS OF AUSTRALIA.* Angus and Robertson, Australia.

Woollard, P., Vestjens, W.J.M. & Maclean, L., 1978: The ecology of the eastern water rat, *Hydromys chrysogaster* at Griffith, N.S.W.: food and feeding habits. *Aust. Wildl. Res.* 5: 59–73.

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SEASONAL DISTRIBUTION PATTERNS OF FISHES WITHIN THE BATHURST HARBOUR ESTUARY, SOUTHWESTERN TASMANIA

by Graham J. Edgar

(with four tables and six text-figures)

EDGAR, G.J., 1991 (20:xii): Seasonal distribution patterns of fishes within the Bathurst Harbour estuary, southwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 37–44. ISSN 0080–4703. Zoology Department, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001.

The distribution of fishes within the Bathurst Harbour estuary was surveyed by gillnet on five occasions and by seine on three occasions, between October 1988 and July 1989. Fish distributions did not noticeably change within the estuary in response to seasonal changes in salinity. A number of fishes were, however, possibly prevented from entering the estuary during February 1989 because of low oxygen concentrations then prevailing. The assemblage of Bathurst Harbour fishes collected by gillnet was unusual in being dominated by sharks and skates, with all of the common species also being distributed in water depths >50 m along the continental shelf. Thus it has many characteristics typical of a deep water assemblage. Included amongst the Bathurst Harbour fishes was a previously unknown species of skate which may be restricted to the estuary. By far the most common of the larger fishes was the white-spotted dogfish *Squalus acanthias*; this species comprised 86% of the total gillnet catch. Despite these large catches, a tagging study in which a very high proportion (25%) of tagged dogfish were recaptured indicated that the total population in the estuary was not exceptionally large, being in the order of only 2900 animals. Tagged dogfish roamed widely through the estuary.

Key Words: Bathurst Harbour, Port Davey, fish, seine, estuary, species richness, *Squalus acanthias*, *Raja* sp., Tasmania

INTRODUCTION

The Port Davey/Bathurst Harbour estuarine system has a number of unusual features. It is the southernmost large estuary in Australia, and is one of only three large Australian estuaries which are highly stratified, with a darkly-stained, brackish surface layer overlying clear marine bottom waters (the others being Macquarie Harbour and the Huon River estuary — Edgar & Cresswell 1991). The area is also isolated and consequently remains the least anthropogenically disturbed large estuary in southern Australia. As part of the first study of the major hydrological and biological components of the Bathurst Harbour estuary (Edgar 1991, Edgar & Cresswell 1991), the distribution of fishes was investigated between October 1988 and July 1989, with the results described here.

The fish fauna of Port Davey and Bathurst Channel has been previously surveyed during short visits by B. Hutchins (Museum of Western Australia), P. Last (Tasmanian Fisheries Development Authority) and G. Edgar (National Parks and Wildlife Service). A checklist of fish species recorded during these surveys and other sources was subsequently compiled (Edgar 1984). A total of only 73 fish species had been recorded from the Port Davey/Bathurst Harbour region prior to the present study. The ichthyofauna is thus depauperate compared to other large estuaries, presumably because of its southern location.

METHODS

Seine Netting

Fishes were collected using a 50 m long beach seine (12 mm mesh) set in a semicircular arc from the beach. A total of 24 sites from Bathurst Harbour to Kelly Basin were sampled from 27 to 29 July 1989, 23 of these sites from 16 to 18 February 1989, and 18 sites from 29 to 30 November 1988. The locations of the sites are shown in figure 1. The abundances of fishes at each site were recorded using a log 3 abundance ranking scale (as in table 1). Two replicate hauls were conducted at each site.

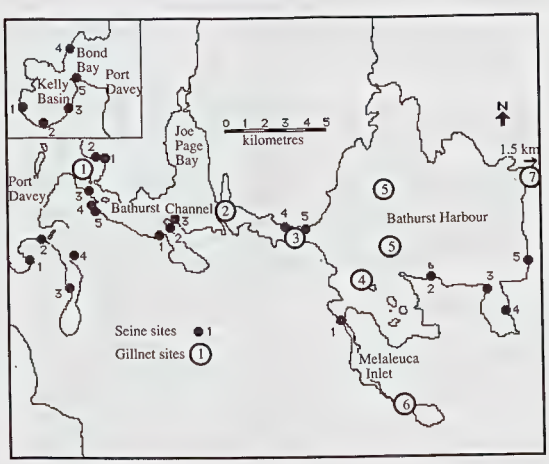


FIG. 1 — Locations of fish sampling sites. Seine sites are separately numbered in five areas: Kelly Basin, Hannant Inlet, Bathurst Channel West, Bathurst Channel East and Bathurst Harbour (see table 1). Gillnet sites: 1 – Channel Entrance; 2 – Bathurst Narrows; 3 – Eastern Bathurst Channel; 4 –Celery Top Islands; 5 – Bathurst Harbour (northern and southern sections); 6 – Melaleuca Inlet; 7 – Old River.

TABLE 1

Mean abundances of fish species collected by seine net during November, February and July field trips.

Abundances are recorded on a log 3 abundance scale (i.e. 1 indicates 1 individual, 2 indicates 2-3 individuals, 3 indicates 4-9 individuals, etc.). Blank spaces indicate no fish were collected, dashes that no sample was made. Site locations are shown in fig. 5.1. Taxonomic authorites are listed by Last *et al.* (1983).

Species	Month	Kelly Basin					Hannant Inlet				Bathurst Channel West					Bathurst Channel East					Bathurst Harbour				
		1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Raja lemprieri	Feb				-								1	1											
Retropinna tasmanica	Dec	-	-			-	-						-	-						3			3		
	Feb				-								1						1	1	1		4	2	
	Jul																		1		1	3	3	3	2
Lovettia sealii	Feb				-																				1
	Jul								1																
Galaxias maculatus	Dec	-	-			-	-			1			-	-							3	1	3		
	Feb				-					2			3		2	1			3		4			2	
	Jul															1					1	4	1		1
Hyporhamphus melanochir	Dec	-	-	1		-	-						-	-											
Atherinasoma microstoma	Dec	-	-	4	3	-	-	1	6				-	-		7	6			3	4		3	4	
	Feb		3		-				7	2				1		7	5		4	4	4	2		4	5
	Jul	9			2										2		3			3		3		1	5
Kestratherina brevirostris	Dec	-	-	1		-	-	-					-	-											
	Feb	2			-																				
	Jul	2	2											3											
Leptatherina	Dec	-	-	5	6	-	-		4				-	-					2	7			6		
presbyteroides	Feb	5	6	7	-	8	6	5		5	4	7	6	7	6			6	4	5		4	4	5	3
	Jul	1	4	8	5	8	5	4	7	7			3	6	7	4	8	5	6	6	6	1		4	2
Hippocampus abdominalis	Dec	-	-		-		-						-	-					1	1					
	Feb				-												1			1					
	Jul																			1					
Mitotichthys semistriatus	Feb				-										1										
Stigmatopora argus	Dec	-	-			-	-		1				-	-											
	Feb										1			1	1					1		1		1	
Gymnapistes marmoratus	Feb	5	6														4		1						
	Jul	5	2																1						
Platycephalus bassensis	Feb		1		-																				
Arripis trutta	Dec	-	-	3	1	-	-	4			5	5	-	-	5										
	Feb		1	2	-	1	2				3														
	Jul			1		2	3	5		4	3	1		2	1			1							
Aldrichetta forsteri	Dec	-	-	2		-	-	2		5		6	-	-						1					
	Feb	2		3	-	2	2				3	3													
	Jul				6	2	4	1		4	3	1		3				3		5					
Neoodax balteatus	Feb	5	6										1	5	1	1	5		1	2		4			
	Jul	5	3													1	3								
Leseurina sp.	Dec	-	-		1	-	-	3					-	-											
	Feb				-		2	3																	
	Jul						1	3																	
Pseudophritis urvillii	Dec	-	-			-	-						-	-		2	2		3	2	3	2			1
	Feb	3	1		-				3					2		2	3		3	3	4	3	1	2	4
	Jul	3	3																		3			1	2
Cristiceps australis	Feb		2	1					1	1			2	2			2			1					
	Jul								1																
Heteroclinus perspicillatus	Feb	1	1		-																				
	Jul	1							1																
*Nesogobius hindsbyi**	Dec	-	-	4		-	-						-	-	3	4	4		3						
	Feb	4	5	5									6	4	4	4	4	4	3	2			2		
	Jul	2	3	4									4	3	2				2	2		1			1
Nesogobius sp.1*	Dec		-	-		-	-		5	3	2		-	-											
	Feb				-				3	3	2														
	Jul					3			1		1			3		2	2		2						
Ammotretis lituratа	Dec	-	-	3	2	-	-				1		-	-											
	Feb			1	-		2	4			1														
Ammotretis rostratus	Dec	-	-			-	-			4		1													
	Feb			4	-		2			4		3	-	-				1							
	Jul			2	1	3	1			3	2	5	2					2							5
Rhombosolea tapirina	Dec	-	-	3		-	-			3		4													1
	Feb	2		3					1			3	-	-		1					1				1
	Jul			1		3	1			3	1	2												1	3
											1	1						1							

Table 1 cont.

Species	Month	Kelly Basin					Hannant Inlet				Bathurst Channel West					Bathurst Channel East					Bathurst Harbour				
		1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Acanthaluteres	Feb			5						1					3			3		2	4					
spilomelanurus	Jul	3	3																						
Contusus brevicaudus	Jul						1																		
Contusus richei	Jul						1				3	1													
Torquigener glaber	Dec	-	-	2		-	-					1	-	-	1	1	2		2	1				7	
	Feb	2	1	4	-		3		1	3	8	8	5	5	7	7	6	4	3	3	5	3	3	4	3
	Jul	1		5		1	3	2	1	2	2	4	4	1	2	2	2	3	1	3		3	1	1	2

* The two *Nesogobius* species were difficult to distinguish at some sites, particularly when small, so it is possible that some specimens may have been assigned to the wrong species.

Gillnetting

Gillnets (50 m long, 105 mm mesh) were set overnight in seven areas along the Bathurst Harbour estuary: Old River, Melaleuca Inlet, Bathurst Harbour, Celery Top Islands, Eastern Bathurst Channel, Bathurst Narrows and Bathurst Channel entrance (fig. 1). Four replicate nets were generally set in each area during the five field trips (October 1988, November/December1988, February 1989, May 1989 and July 1989), with the following exceptions: Eastern Bathurst Channel in October (two replicates only), December (3) and May (2); Bathurst Harbour in October (2); Melaleuca Inlet in May (2); and the Old River (not sampled in February, May or July). The Bathurst Harbour site was separated into northern and southern sections; two nets were placed in each section except during October, when the southern section only was sampled.

Because a single species, the white-spotted dogfish (*Squalus acanthias*), dominated the catches at all sites and was clearly a key component of the Bathurst Harbour ecosystem, some basic life-history research was conducted on this species. A total of 108 individuals from five sites were tagged by placing yellow plastic cattle eartags in the baso-distal section of the first dorsal fin, by recording their fork length and sex. Whenever tagged individuals were recaptured their length was remeasured and locality recorded. The size-frequency distribution of *S. acanthias* within the estuary was determined during the July 1989 field trip by measuring the length and determining the sex of all captured dogfish.

Statistical Analysis

Sites were classified by calculating a similarity matrix between pairs of sites using the Pearson correlation coefficient. The information in the similarity matrix has been hierarchically grouped using average linkage and presented as a dendrogram. A corresponding inverse analysis for fishes using the same data set was also made.

RESULTS

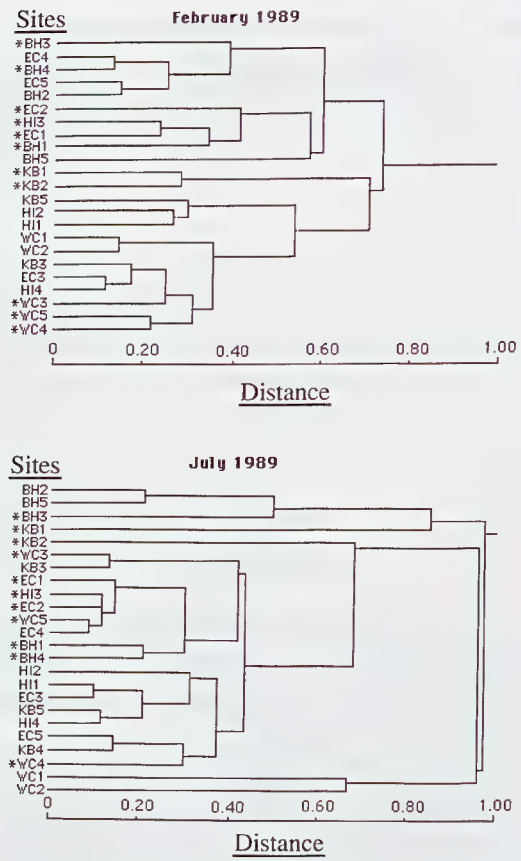
Seine Netting

A total of 29 fish species was collected by beach seine from the Bathurst Harbour estuary and Kelly Basin (table 1). Slightly more species were collected during the February survey (26) than during July (23), even though one more site was sampled on the latter occasion.

Three major groupings of sites are apparent when sites are classified by their February fish faunas (fig. 2). The two sheltered Kelly Basin sites (KB1 and KB2) were quite different to other sites. These sites both contained relatively diverse assemblages of fishes associated with seagrass beds. The other major division between sites was between locations east and west of the centre of Bathurst Channel; the only two exceptions to this major dichotomy were that Balmoral Beach (EC3), an exposed sandy beach in eastern Bathurst Channel, grouped with western Bathurst Channel sites, and the Hannant Inlet south site (HI3) grouped with eastern Bathurst Channel sites.

During July, sites separated much more on the physical characteristics of the site rather than on geographic position. Separate major groupings occurred between sites with fine sediment (silt and clay) and sites with coarse sediment (pebbles and sand) within the estuary (fig. 2). The Kelly Basin sites, three of the Bathurst Harbour sites and the Bramble Cove sites in Bathurst Channel showed little similarity with other sites.

The inverse classification of the February and July data sets showed analagous patterns to the site classification (fig. 3). During February, the two major groups of fishes were those associated with sites adjacent to Port Davey and those associated with sites further up the estuary, while in July, habitat type was much more important. The three major groups of fishes in July included a fine sediment and seagrass associated group, a coarse sediment group, and a group found only in the upper reaches of the estuary. The latter group contained two species only (*Galaxias maculatus* and *Retropinna tasmanica*). The coarse sediment group was the least homogeneous, with marine-influenced species (*Aldrichetta forsteri, Contusus richei, Arripis trutta* and *Leseurina* sp.) linking to more estuarine species at a relatively low level of similarity (fig. 3).



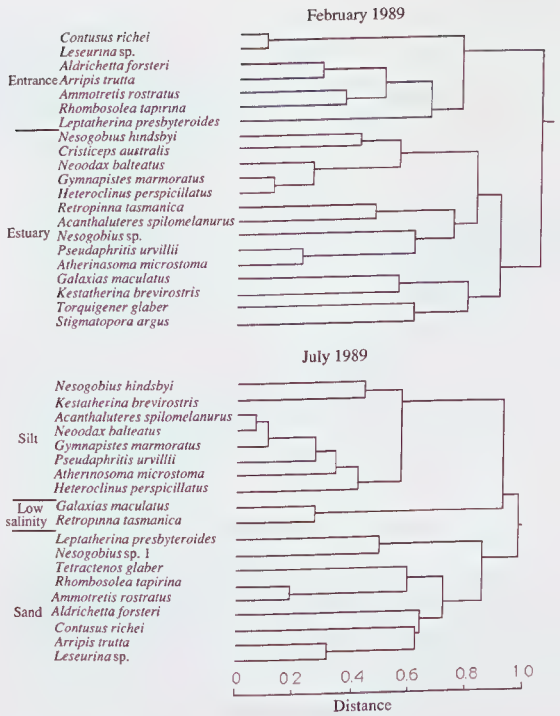


FIG. 3 — Inverse classification of February and July beach seine data.

*FIG. 2 — Classification of sites using beach seine data. Sites are listed by area (Kelly Basin, KB; Hannant Inlet, HI; West Bathurst Channel, WC; East Bathurst Channel, EC; Bathurst Harbour, BH) and site number (fig. 5.1). * indicates that site has fine-sediment substratum.*

The diversity of fishes collected by beach seine was related to both the salinity and substratum type of the habitat. The number of species collected from sites with soft sediments decreased up the estuary, while the opposite trend was found at sites with coarse sediments. This is shown in fig. 4 where the total number of fishes collected at each site is plotted against the winter (July) salinity. The difference between these two regressions was found to be highly significant ($P<0.01$) using Analysis of Covariance (table 2). Note that, although salinity and substratum type were related to fish diversity in this analysis, the analysis does not indicate that either of these factors were directly responsible for fish distribution patterns. Other physical factors were strongly correlated with salinity and substratum type; for example, wave exposure was correlated with sediment type and nitrate levels with surface salinity, so the effects of particular physical factors could not be separated.

Gillnetting

Fishes collected during the gillnetting survey are listed in table 3. Almost all of these species are widely distributed around Tasmania. The only surprising catch was a previously unknown species of skate collected from the centre of Bathurst Harbour. Three specimens of this fish were caught during the study, two of them being retained and lodged at CSIRO, Division of Fisheries. The species shows closest similarity to the New Zealand skate *Raja nasuta*, but reaches maturity at a much smaller size (P.R. Last, pers. comm.).

Sharks and rays dominated the fish assemblage in the Bathurst Harbour estuary. The ten elasmobranch species collected by gillnet included the three most common fishes and also 95% of total fish numbers. The white-spotted dogfish *Squalus acanthias* was by far the most abundant large species in the area, comprising 86% of the total catch. Teleosts were most common at the western entrance to Bathurst Channel; however, even at this site they were less abundant than sharks.

Very few fish were collected in areas with considerable freshwater input, i.e. the Old River and Melaleuca Inlet. Eels were probably the dominant fish in these areas but were virtually impossible to catch using gillnets. Few species were also found in the centre of Bathurst Harbour, probably because of the lack of rocky substrata in the area. The abundance of dogfish in this area was, however, extremely high.

The population structure of *Squalus acanthias* differed markedly between different sites in the estuary (fig. 5). Large females and immature juveniles were collected at the Port Davey entrance to Bathurst Channel in July 1989, with mature males and a few small juveniles being found in Bathurst Harbour. The central area of Bathurst Channel was an overlap area in which the two groups of animals

TABLE 2
Results of analysis of covariance

Compares the regressions relating total number of fish species collected by seining at a site and the winter (July 1989) salinity of the site for coarse sediment (cobbles/sand) and fine sediment (silt/mud) habitats.

Effect	d.f.	MS	F	P
Substrate	1	25.44	8.80	0.008
Salinity	1	3.47	1.20	0.287
Substrate × salinity	1	35.05	12.12	0.002
Error	19	2.89		

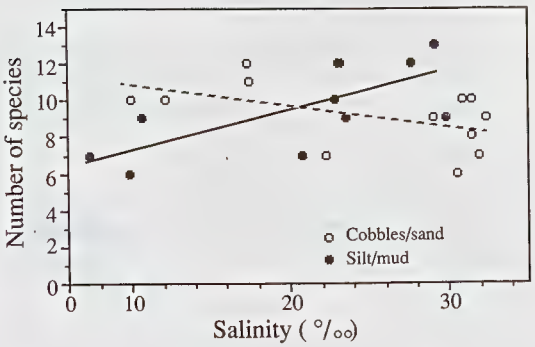


FIG. 4 — The relationships between the number of fishes collected by beach seine at different sites and the winter (July 1989) salinity at those sites for two different habitat types: coarse-sediment (cobbles/sand) and fine-sediment (silt/mud) substrata.

TABLE 3
Number of fishes collected in gillnets set at different sites

Site	Old River	Melaleuca Inlet	Bathurst Harbour	Celery Top Islands	Eastern Bathurst Channel	Bathurst Narrows	Channel Entrance	Total
Number of nettings	8	18	18	20	15	20	20	119
Species								
Heterodontus portusjacksoni	0	0	0	0	0	1	0	1
Notorhynchus cepedianus	0	0	0	0	0	0	3	3
Cephaloscyllium laticeps	0	0	0	0	0	0	2	2
Galeorhinus galeus	0	0	0	0	1	1	1	3
Mustelus antarcticus	0	0	3	14	19	24	6	66
Squalus acanthias	0	0	687	190	149	316	89	1431
Raja lemprieri	0	0	0	0	1	0	0	1
Raja whitleyi	0	0	0	1	0	0	0	2
Raja sp.	0	0	3	0	0	0	0	3
Callorhynchus millii	0	0	3	13	24	5	1	46
Anguilla australis	0	1	0	0	0	0	0	1
Pseudophycis bachus	0	4	4	9	8	11	4	40
Pseudophycis barbatus	0	0	0	0	0	0	1	1
Cyttus australis	0	0	0	0	0	0	3	3
Hippocampus abdominalis	1	0	0	0	0	0	0	1
Stigmatopora argus	0	0	0	1	0	1	0	2
Neosebastes scorpaenoides	0	0	0	2	2	2	9	15
Cheilidonichthys kumu	1	2	0	7	3	0	0	13
Platycephalus bassensis	0	0	0	1	2	3	0	6
Pentaceropsis recurvirostris	0	0	0	0	0	0	1	1
Nemadactylus macropterus	0	0	0	2	0	0	0	2
Latridopsis forsteri	0	0	0	0	0	8	8	16
Notolabrus fucicola	0	0	0	0	0	2	1	3
Number of species	2	3	5	10	9	11	14	23

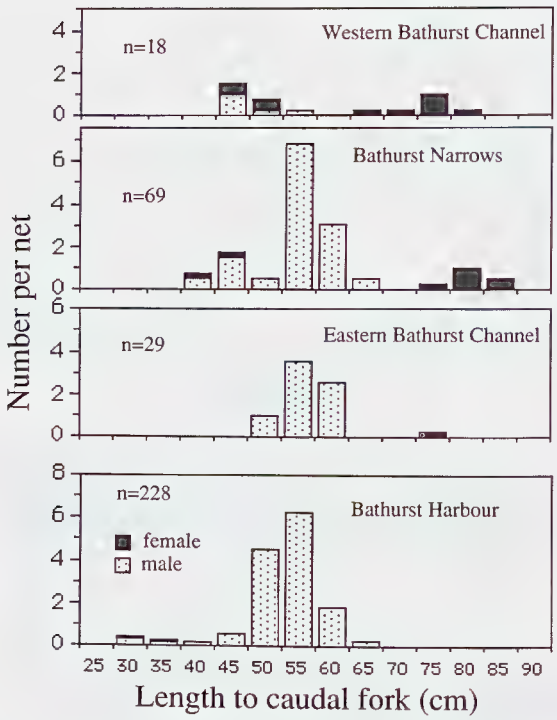


FIG. 5 — Mean number of white-spotted dogfish in different size-classes collected per net in different areas of the Bathurst Harbour estuary in July 1989. The Celery Top Island and Bathurst Harbour data have been combined. n = total number of animals collected.

coexisted. These size-distribution patterns did not remain constant throughout the year, however, as no large females were collected in February. Many of the large females were pregnant, one of them releasing four young after capture at Bathurst Narrows in November. The Bathurst Harbour estuary may be used for mating as well as spawning. Almost all large males were mature, releasing sperm on capture.

An extremely high proportion of tagged dogfish were recaptured. Of the total of 108 tagged animals, 27 (= 25%) were recaptured during the study (i.e. the 25 shown in table 4 and two recaptured in December). A further three tagged fishes were caught by visiting fishermen. Most of the recaptured animals were taken at sites away from their release points, in three cases at the other end of the estuary (fig. 6). No obvious patterns were evident in the movement of animals, dogfish from any site having approximately equal probability of being recaptured at any other site in the area (fig. 6).

A small number (11) of gummy shark, *Mustelus antarcticus*, were also tagged and released during the study in Bathurst Channel. Two of these sharks were recaptured two months after release near where they were tagged, at Platypus Point and Gull Islet at the eastern end of Bathurst Channel.

DISCUSSION

The two methods of fish sampling, beach seining and gillnetting, yielded different faunas. Only four species, thornback skate *Raja lemprieri*, sand flathead *Platycephalus bassensis*, spotted pipefish *Stigmatopora argus* and wide-bellied seahorse *Hippocampus abdominalis*, were collected using both methods. Because no prior gillnetting study had been done in the Bathurst Harbour estuary, many of the fishes collected using this technique were new to the area (10 species). Beach

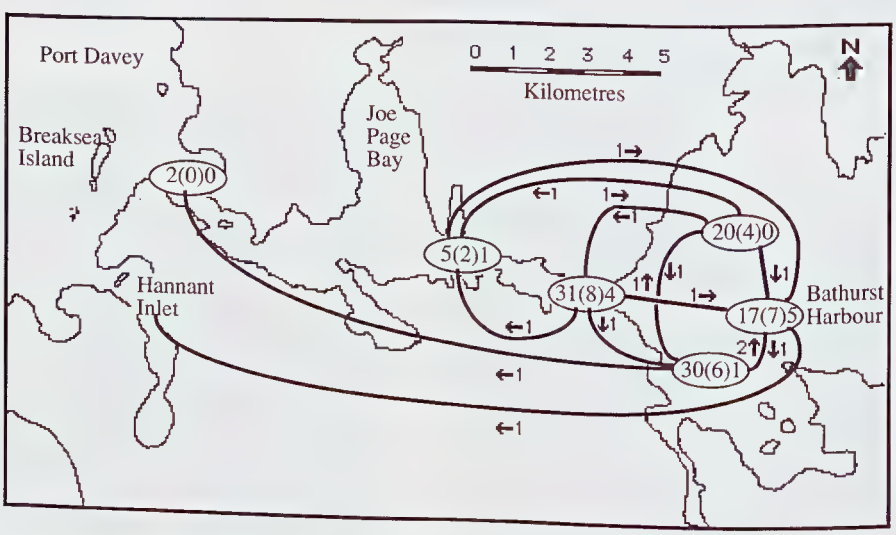


FIG. 6 — Movement of tagged white-spotted dogfish in the Bathurst Harbour estuary. For each site the total number of dogfish released at that site is initially shown (followed by the number which were tagged at that site and later recaptured) followed by the number recaptured at the same site. One individual, not shown on the figure, was released at Celery Top Islands and recaptured in Bond Bay, northwestern Port Davey.

seining provided seven additions to the list of fishes previously known for the Port Davey region (Last 1983, Edgar 1984). The only notable new record collected by seine was the Tasmanian whitebait, *Lovettia sealii*, a species which has been commercially overexploited elsewhere in Tasmania (Last *et al.* 1983). Even though only two specimens of *L. sealii* were collected during the study, this fish may occur in high population densities in Bathurst Harbour, since its open water habitat was not adequately sampled using a seine net and specimens could easily pass through the 12 mm net mesh.

The other notable species collected during the study was the undescribed species of skate (*Raja* sp.) taken in Bathurst Harbour. The restricted range of this ray is extremely unusual for a marine fish, so it is possible that the species also occurs in deeper waters off the Tasmanian coast. It is, however, also possible that the species is confined to Bathurst Harbour, because extensive trawl surveys made around Tasmania during the past decade would be expected to have yielded the species, if at all widespread (P.R. Last, pers. comm.), particularly as all other Australian skates which occur in shallow water have been collected on numerous occasions. The only estuarine locality outside Bathurst Harbour in which the skate is likely to occur is Macquarie Harbour. During a gillnet survey of Macquarie Harbour by the Division of Sea Fisheries and the Inland Fisheries Commission, a number of skates were collected which may have been the undescribed species but were assumed to be the common thornback skate (*Raja lemprieri*), so were not closely examined (A. Schaap, pers. comm.).

The entire assemblage of larger fishes in the Bathurst Harbour estuary was unusual in being dominated by species which are also commonly found in the deeper waters (>50 m) of the continental shelf. Gillnet samples were dominated, both in species and population numbers, by elasmobranchs. Sharks and rays generally increase in abundance and species richness offshore (Last & Harris 1981). *Squalus acanthias*, the most abundant species in Bathurst Harbour, has been found below 700 m (Hart 1973). The three common teleosts collected by gillnet, red gurnard *Cheilidonichthys kumu*, gurnard perch *Neosebastes scorpaenoides* and red cod *Pseudophycis bachus*, have also all been commonly recorded on the continental shelf below 50 m depth (Last & Harris 1981).

Low oxygen concentrations within the estuary during February 1989 (Edgar & Cresswell 1991) probably greatly affected the distribution of fishes, preventing a number of species from entering the estuary and causing the beach-seined sites to group on a geographic Port Davey/Bathurst Harbour basis rather than a habitat basis (fig. 2). The recorded oxygen levels (≈35% saturation; Edgar & Cresswell 1991) were certainly lower than salmonids can withstand for long periods (Alabaster & Lloyd 1983), a possible reason for trout not being recorded from the area. It is notable that all of the large active teleosts collected by beach seine and gillnet (i.e. the Australian salmon *Arripis trutta*, yellow-eye mullet *Aldrichetta forsteri*, bastard trumpeter *Latridopsis forsteri*, morwong *Nemadactylus macropterus* and purple wrasse *Notolabrus fucicola*) were not taken past Bramble Cove in summer but were found through Bathurst Channel in other seasons. Salinity is clearly not the primary environmental factor affecting species distribution in the area or the opposite trends would have been found, with marine species penetrating up the estuary in greatest numbers in summer.

The general decrease in the number of fish species collected by beach seine from sandy habitats as one moves toward the sea (fig. 4) was unexpected as it is contrary to the trends for fine-sediment associated fishes (fig. 4), gillnetted fishes (table 3), and planktonic (Edgar & Cresswell 1991) and benthic taxa (Edgar 1991). Perhaps this increase was trophically related; in contrast to fishes in silt habitats, most of the fishes collected from sand and cobbles were planktivorous open-water fishes and the abundances of planktonic prey rapidly increased up the estuary (Edgar & Cresswell 1991). Species associated with fine-sediment habitats probably decreased up the estuary primarily because dense seagrass beds occurred on silt sediments only in marine areas, with seagrasses becoming quite sparse in less saline waters. A component of fish species was commonly found only in association with seagrasses (e.g. *Gymnapistes marmoratus, Neoodax balteatus*).

The life history of the white-spotted dogfish, *Squalus acanthias*, is probably better known than any other shark. The species has been intensively studied because of its commercial importance and wide distribution around the world. Most of the information pertaining to the biology of this species has been summarised by Compagno (1984), who reported that:

(i) *S. acanthias* cannot survive freshwater for more than a few hours but tolerates brackish water;
(ii) it is a slow-growing species which is very long lived;
(iii) the species occurs in schools which are segregated by sex;
(iv) only males and large pregnant females generally occur in shallow water;
(v) pregnant females congregate in enclosed shallow bays where they release 1 to 20 young; and
(vi) the species prefers water between 7°C and 15°C, making latitududinal and depth migrations to stay within the optimal range.

In all respects this information agrees with observations made during the present study:

(i) *S. acanthias* was not collected in Melaleuca Inlet or the Old River but was widespread in the more marine sections of the estuary;
(ii) tagged individuals were slow growing, with many tagged animals not increasing in length while liberated and the fastest-growing animal increasing only 20 mm in 8 months;
(iii) large numbers of fishes were collected in small sections of gillnet, indicating a schooling habit, and there was also a clear size separation of stocks within the estuary (fig. 5);
(iv) intermediate-sized (55-65 cm) females were not collected;
(v) large pregnant females were found along Bathurst Channel between July and November, including one animal which released four young when brought into the boat; and
(vi) numbers of captured animals were lowest during the summer survey, the period when water temperatures fell outside the preferred 7–15 °C range.

Although the very high numbers of dogfish captured in Bathurst Harbour suggest that an extremely large population exists in the area, the high proportion of tagged animals which were recaptured belies this. *Squalus acanthias* are slow swimmers, which keep a regular pace in their nomadic movements (Compagno 1984). They wandered throughout the estuary rather than remained in localised populations (fig. 6). The high capture rates, therefore, appear to have had as much to do with dogfish behaviour as with population densities. During each night an individual dogfish probably travels several kilometres, and thus has an appreciable probability of encountering a set net. Approximately 10%

TABLE 4
Numbers* of *Squalus acanthias* captured, tagged and recaptured during the February, May and July 1989 gillnet surveys

	Feb	May	Jul
Number of captured animals	198	291	346
Number of tagged animals recaptured	8†	10†	7
Number of tagged animals previously released	65	101	108
Number of surviving tagged animals	64	92	92
Population estimate	1609	2677	4547

* Population estimates based on these numbers are also given. The number of surviving tagged animals is the number of tagged animals released less the number of tagged animals which had died on recapture during a previous survey, e.g. 108 animals had been released prior to the May survey, 16 of which had been recaptured and not rereleased. Three tagged dogfish, which are not listed here but are incorporated into figure 6, were recaptured by yachtsmen.
† Two fish were collected in February and another in May with their dorsal fins hole punched and torn. These fish had lost their tags and are included in the total.

of previously tagged fish were recaptured (table 4) during each survey, with a mean of 2900 animals estimated to have been present in Bathurst Harbour and Bathurst Channel over the three survey periods (table 4). However, this population number may be overestimated, because calculations did not take into account any handling or tag-induced mortality of released animals, and this could well have been considerable. Assuming that the total population in the 60 km^2 area of the Bathurst Harbour estuary was 2900 fish, each overnight set of a gillnet in Bathurst Harbour caught ≈1.3% of the total population (i.e. 38 fish). Netting within the estuary therefore appears to significantly affect local population numbers.

ACKNOWLEDGEMENTS

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REFERENCES

ALABASTER, J.S. & LLOYD, R., 1983: *WATER QUALITY CRITERIA FOR FRESHWATER FISH.* 2nd edn, FAO Butterworths.

COMPAGNO, L.J.V., 1984: *AN ANNOTATED AND ILLUSTRATED CATALOGUE OF SHARK SPECIES KNOWN TO DATE. PART 1. HEXANCHIFORMES TO LAMNIFORMES. FAO Species Catalogue Vol. 4. Sharks of the World.* FAO, Rome.

EDGAR, G.J., 1984: Marine life and potential marine reserves in Tasmania. Part 2. *Nat. Parks Wildl. Serv. Occ. Pap.* 7: 1-102.

EDGAR, G.J., 1991: The distribution of mobile epifauna associated with rope fibre habitats within the Bathurst Harbour estuary, south-western Tasmania. *Estuar. Coast. Shelf Sci.*, in press.

EDGAR, G.J. & CRESSWELL, G.R., 1991. Seasonal changes in hydrology and the distribution of plankton in the Bathurst Harbour estuary, southwestern Tasmania. 1988-1989. *Pap. Proc. R. Soc. Tasm.* 125: 000–000.

HART, J.L., 1973. Pacific fishes of Canada. *Bull. Fish. Mar. Board Can.* 180: 1-740.

LAST, P.R., 1983. Aspects of the ecology and zoogeography of fishes from soft-bottom habitats of the Tasmanian shore zone. Unpubl. Ph.D. thesis, University of Tasmania.

LAST P.R. & HARRIS, J.G.K., 1981: New locality records and preliminary information on demersal fish faunal assemblages in Tasmanian waters. *Pap. Proc. R. Soc. Tasm.* 115:189-209.

LAST, P.R., SCOTT, E.O.G. & TALBOT, F.H., 1983: *FISHES OF TASMANIA.* Tasmanian Fisheries Development Authority, Hobart.

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THE FORM OF THE HAIR FOLLICLE IN THE HUMAN SCALP AS AN INDICATOR OF HUMAN RELATIONSHIPS

by Brian Plomley and Les Barber

(with two tables and nine plates)

PLOMLEY, B. & BARBER, L., 1991 (20:xii): The form of the hair follicle in the human scalp as an indicator of human relationships. *Pap. Proc. R. Soc. Tasm.* 125: 45–54. ISSN 0080–4703. Queen Victoria Museum and Art Gallery, Launceston, Tasmania, Australia 7250 (BP); and Department of Medical Sciences, University of Tasmania, Newnham Drive, Newnham, Tasmania, Australia 7248 (LB).

The form of the hair follicle has been examined in some human isolates. There is no relationship between follicular structure and hair form, that is, similar hair forms may be the end product of different follicular structures. Such diversity means that it is not possible to use hair form as an indicator of human relationships. The usefulness of follicular structure as such an indicator must await a much wider sampling from an extensive variety of human isolates.

Key Words: hair follicle, Andaman, Australian aboriginal, Bantu, Bushman, Chinese, New Guinea, Tasmanian aboriginal, Zulu, Australia.

INTRODUCTION

A concern with human relationships has long been of importance to humans. Probably this had its origins in feelings of superiority of one group over another, feelings which then became associated with religion. It was not until the 18th century in Europe that the study of human relationships became of interest to savants and took on a scientific manner of thinking. Different peoples were considered to have developed as isolates of a single creation by God, and it was thought that scientific studies might reveal the interrelations of the various groups. Several basic forms were postulated, the so-called races of *Homo sapiens*, and their distribution was related to the pathways of migration of humans over the Earth.

The form of the hair of the scalp and the colour of the skin were the first characteristics of the human body to be considered as indicators of human relationships. The colour of the skin was early found difficult to systematise and was used only to differentiate socially between so-called superior beings having white skins and inferior ones with black skins. It is not to be wondered at that skin colour defied classification when the production of melanin pigments is genetically so complex.

An association between the form of the scalp hair and human groups was noticed by the ancient Greeks, the historian Herodotus drawing attention to it in respect of the soldiers composing the army of Xerxes (*The Histories*, book VII). The first attempts to formulate such differences in systems of classification were made by French scientists of the late 18th century. These systems have been revised from time to time since then, in attempts to make them fit better the complexity of human relationships, but none has been found which provides a sound basis for the classification of humans (Trotter 1938).

The attempts to use hair form and skin colour were early supplemented by the use of the form of the human skull as an indicator of human relationships. Johan Friedrich Blumenbach (1752–1840), Professor in the Faculty of Medicine at Göttingen, was the pioneer of such studies, and his research led to the formation, in the 19th century, of vast collections of human crania, which are scattered through many museums over the world. These 19th-century collections are especially valuable because their material had come from peoples at a time when many of them had mingled only to a limited extent with foreigners, so that these collections provide samples of the original populations.

The high hopes entertained of obtaining meaningful data on human relationships from cranial studies did not eventuate. Basically, this was because relationships between the two parts of the skull, that is, the braincase and the facial skeleton, are complex. As a result, much of the early research was too crude to have much meaning. However, developments in statistical theory have enabled students to deal with cranial measurements in such a way that they have some relevance.

With the discovery of the genetic mechanism of inheritance and the elaboration of methods for the study of the human blood groups, another approach to the study of human relationships was opened up. Such studies have provided information about relationships between neighbouring peoples. In the future, it may be expected that new techniques will allow comparisons to be made between groups by the use of body fluids and tissues, mummified organs and bone, and in these, early collections of human remains will play an important part.

FORM OF THE SCALP HAIR

Systems of classification of the form of the scalp hair have been based upon on the nature of the hair, that is, whether it hangs straight, is waved or curls in ringlets. An explanation of these various types has been sought, largely in terms of the cross-section of the hair and/or the structure of the follicle which produces and carries the hair from the germinal bulb to the surface of the scalp. It is clear, however, that, over the whole time it is growing, the type of hair will not only be influenced by what occurs in the bulb, but is likely, also, to be affected by the follicle — its form, its length and the activity of the sebaceous glands — as well as by the changes in the chemical nature of the keratins which compose the hair during the time it is moving from the bulb to the surface of the scalp. In addition, there will be many indirect influences,

such as the state of the endocrine system, the health and nutrition of the individual, and so on.

Most research has dealt with the form of the hair rather than with the follicle producing it. Peter Browne was the first, in 1853, to give detailed consideration to the cross-sectional form of the hair (Trotter 1938); he was followed by Pruner-Bey (1864, 1865), with particulars for a wide range of human types. Their work has been followed by a number of other studies (Trotter 1938). Few students thought that the form of the follicle was the principal agent in the development of hair form, finding in general that a straight hair shaft was associated with a round cross-section and a curved shaft with an oval cross-section. In most of these studies, however, only two or a very few different peoples were compared.

The object of the present paper was to study the form of the hair follicle in several different peoples so as to explore human relationships generally in this way. Although the number of different groups studied was small (perhaps also because the samples were too small), the work has produced information which points to ways of differentiating peoples but not to their relationships.

THE MATERIAL

Samples of scalp were obtained from the following peoples and individuals — Andaman (3 individuals), Australian aboriginal (5), Bantu (8), Bushman (9), Chinese (Singapore) (12), New Guinea (11), Tasmanian aboriginal (1), Zulu (24).

Nearly all this material was obtained from autopsies or from medical cadavers and has been preserved in formol saline or in rectified spirit (95% alcohol); a few specimens had been dried.

METHODS OF PREPARATION

Preliminary research, carried out between 1963 and 1967 at the University of New South Wales and at University College, London, was based largely upon serial sections of the scalp, using standard techniques of preparation and staining, and a few whole mounts of slices of scalp were examined to determine the distribution of the follicles. Study of the Tasmanian hair follicle was carried out at this time (Plomley & Baldwin 1964), and the particulars which form part of this paper were recorded then.

In the present study the arrangement of the hair follicles in the scalp was studied in two vertical sections, each about 5 × 2 mm, and full skin thickness, taken at right angles to one another, and a third piece of scalp about 15 × 10 mm, to show the surface of the scalp in relation to the hair. These pieces were then treated as follows: to 70% alcohol for 24 hours; to 95% alcohol for 6–8 hours; to a mixture of equal parts of 95% alcohol and LKB 2218-500 HISTORESIN infiltration solution overnight at room temperature; to full strength HISTORESIN solution for 6 hours. They were then embedded in LKB HISTORESIN embedding medium in a mould; polymerisation occurred within 2 hours and the expelled fluid was drained off the block, which could be removed from the mould after 24 hours. After embedding, the specimens were photographed on Kodak Gold 200 film, using an Olympus stereoscopic microscope.

FORM OF THE FOLLICLE IN SEVERAL ISOLATES

The data on the follicle will be presented first in terms of its size, form, direction and density, and the relationships of bulb and shaft. The principal points of interest in the data are summarised in table 1.

Andaman (Pl.1 A,B)

Size
Thick and fairly uniform.

Form
Markedly curved, the curvatures all in the same sense.

Direction
The follicles approach the surface obliquely at end of their curve; having pierced the surface of the scalp, the hair continues the direction of the follicle.

Density
The follicles arising from the groups of bulbs keep together in the epidermis, so that there are wide spaces between the groups, and they meet on the surface in a pigmented spot.

Bulb
The germinal bulbs are set at an angle to the shaft of the follicle; the bulbs form groups of two or three, usually three.

Australian Aboriginal (Pl.2 A,B)

Size
Differences in diameter not great, the range not approaching the extremes of fine and very thick.

Form
Follicles usually slightly and uniformly curved, but sometimes straight, or nearly so; curves all in the same sense, follicles seldom crossing one another; the follicles arise at different depths.

Direction
Follicles approach surface obliquely, or nearly so; having pierced the surface of the scalp, the hair continues the direction of the follicle.

Density
Intermediate; the germinal bulbs have no specific arrangement, being distributed haphazardly in the epidermis; it is usual for two hairs to emerge from the scalp close to one another (but not as a doublet) on a small pigmented area.

Bulb
The bulbs are clubbed terminally, this part continuing into the shaft of the follicle without a bend.

TABLE 1
Summary of follicular characters for the human isolates examined here

	Andaman	Australian aboriginal	Bantu	Bushman	Chinese (Singapore)	New Guinea		Tasmanian	Zulu
						Highlands	Port Moresby		
Size									
large	x		x		x	x	x	x	
medium		x		x					x
small				x	x				
mixed		x	x		x	x	x		x
Form									
straight					x		x		
slight curve		x					x		
strong curve	x		x	x		x		x	x
Direction									
direct			x		x		x		x
oblique	x	x		x	x	x		x	
Density overall									
heavy			x		x	x	x		
medium	x	x		x	x				x
Density arrangement									
deep-haphazard		x	x		x	x	x		x
deep-doublet, triplet	x			x	x				
surface-haphazard					x	x			
surface-doublet,triplet	x	x	x	x	x		x		x
Bulb type									
shaft straight		x			x			x	
shaft clubbed	x		x	x		x	x		x
Bulb depth									
deep	x	x	x	x	x	x	x		x
mixed		x			x				

Bantu (Pl.3 A,B)

Size
A mixture of diameters, mostly large.

Form
Most follicles strongly and smoothly curved; in some scalps (three) the follicles all curved in same direction, but in others (three) the amount of curving differed and follicles had no definite arrangement.

Direction
Although curved, the follicle approaches the surface of the scalp in such a way that the hair issues from the scalp at right angles to it or nearly so; having pierced the surface, the hair continues the curve of the follicle.

Density
Some variation in density, but high in all; no definite arrangement of follicles apparent in the scalp; doublets common at skin surface.

Bulb
Germinal bulbs set obliquely to shaft and heavily pigmented.

Bushman (Pl. 4 A,B)

Size
Medium to small.

Form
Usually strongly curved, but some less so and almost straight.

Direction
Follicles approach surface more or less obliquely; having pierced the scalp, the hair continues the direction of the follicle.

Density
The groups of follicles keep together in the epidermis, so that there are wide spaces between the groups, which meet at the surface in a pigmented spot.

Bulb
Bulbs not set at angle to shaft of follicle; occur in groups of two (occasionally three ?).

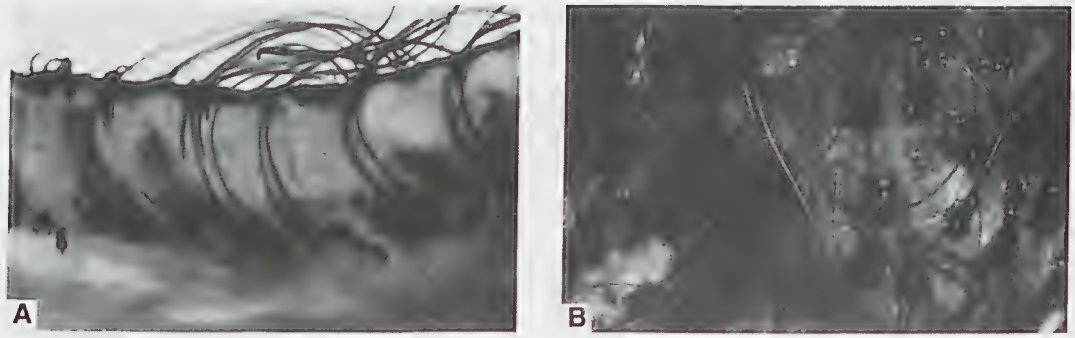

PLATE 1
Andaman: (A) scalp section; (B) scalp surface.

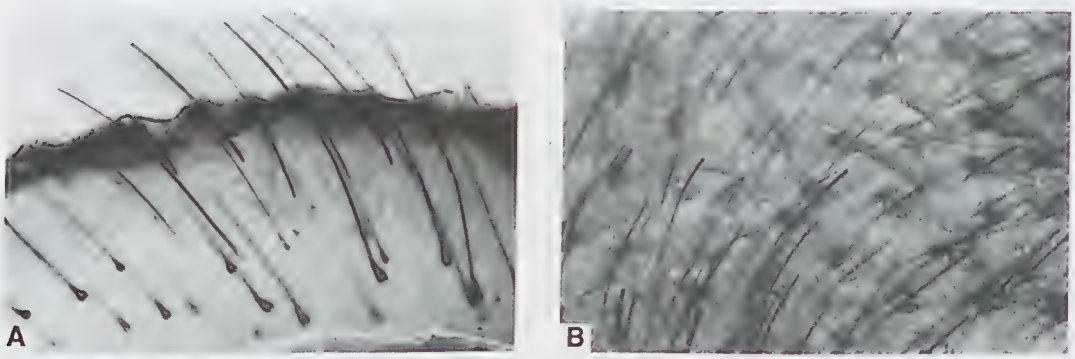

PLATE 2
Australian aboriginal: (A) scalp section; (B) scalp surface.

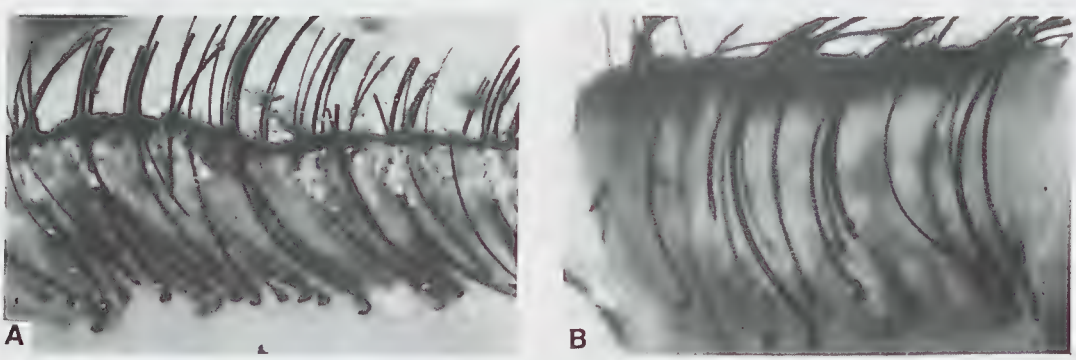

PLATE 3
Bantu: (A) scalp section; (B) scalp section.

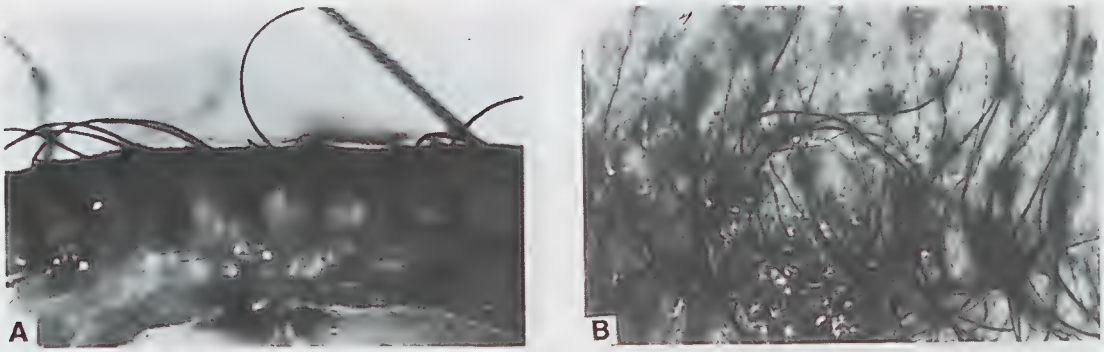

PLATE 4
Bushman: (A) scalp section; (B) scalp surface.

Chinese (Singapore) (Pl. 5 A–F)

Size
Most of the scalps had a mixture of thick and fine hairs, but sometimes diameter uniform and thick.

Form
Straight or nearly so.

Direction
The follicles (and bulbs) may be directed either at right angles to the surface of the scalp, or approach it obliquely; in the latter case, the follicle may be slightly curved. (Is it the obliquely placed follicle which is sometimes found associated with the slight wave of some Chinese scalp hair?)

Density
There is a good deal of variation in follicular density, some scalps having a larger number of follicles per unit area than others, and these may arise over a wide range of depths. When the follicles are sparse their distribution is haphazard, but when dense there is perhaps a tendency to run obliquely to the surface, so that two follicles reaching it side by side appear to form a doublet, with, in one very dense specimen, a regular arrangement of follicles at the surface, clumps of two or three adjacent hairs being distributed in a regular system of squares although the origins of the follicles were haphazard.

Bulb
The bulbs may be set a little obliquely to the shaft, but essentially they continue straight into it.

New Guinea

Woolly hair (Highlands) (Pl.6 A,B)

Size
A mixture of diameters, but mostly thick.

Form
Strongly and smoothly curved, all sizes the same.

Direction
Although strongly curved, the follicle approaches the surface in such a way that the hair issues from the scalp at right angles to it or nearly so; having pierced the surface, the hair continues the curve of the follicle.

Density
About the same in both scalps; there is no definite arrangement of follicles either at their origin or at the surface, where the distribution of hair is both haphazard and uniform.

Bulb
Bulb set obliquely to shaft.

Port Moresby series (Pl. 7 A,B)

Size
A mixture of sizes with large diameters predominant; the latter little different from those of the woolly haired subject.

Form
Follicles either slightly curved or straight (none strongly curved); the hairs protruding from the surface appear to be a mixture of straight and slightly curved forms.

Direction
The follicles meet the scalp at right angles to it or slightly obliquely.

Density
High in all subjects; no definite arrangement at origins; arrangement at surface not clear, but in one subject the hairs issue in doublets which are distributed irregularly.

Bulb
Bulb set obliquely to shaft.

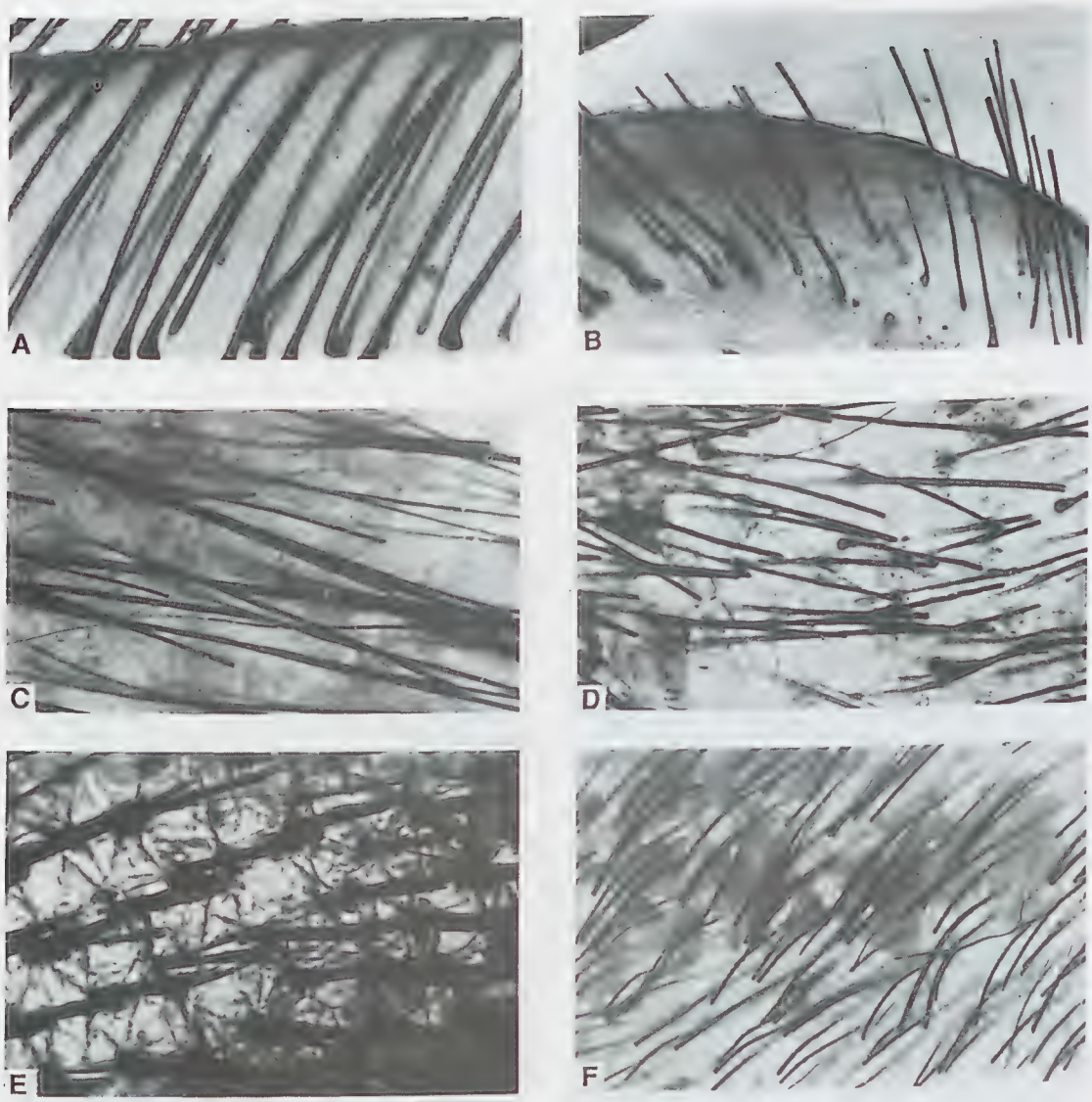

PLATE 5
Chinese: (A) scalp section; (B) scalp section; (C) scalp surface; (D) scalp surface; (E) scalp surface; (F) scalp surface.

Tasmanian (Pl. 8)

Size
Large diameter.

Form
Follicle strongly curved; lies obliquely in scalp.

Direction
Follicle meets surface obliquely, the hair continuing the curvature of the follicle.

Density
Medium.

Bulb
Appears to continue into shaft.

Note
There seems to be a tendency for the follicles at the surface to lie in pairs, with wide spacing between them; deeply, the follicles seem to be distributed haphazardly.

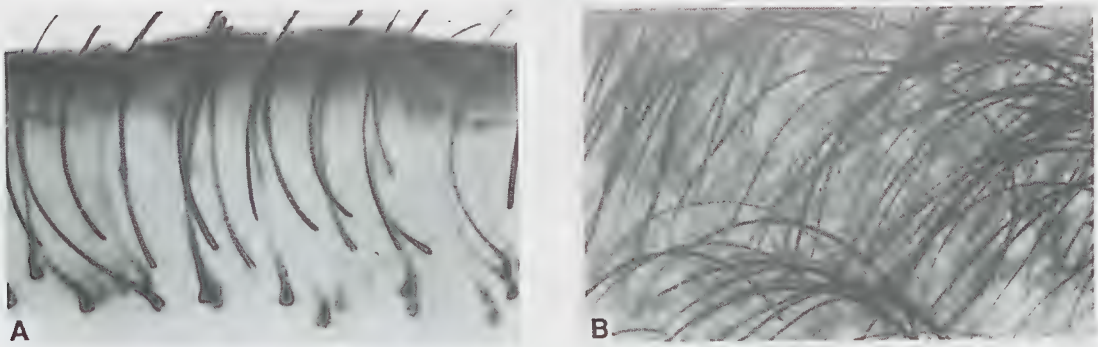

PLATE 6
New Guinea woolly: (A) scalp section; (B) scalp surface.

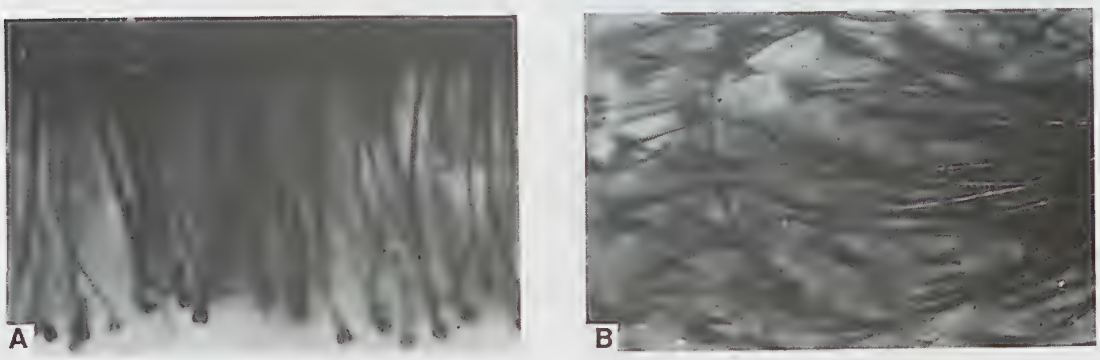

PLATE 7
New Guinea Port Moresby: (A) scalp section; (B) scalp surface.

PLATE 8
Tasmanian: scalp section.

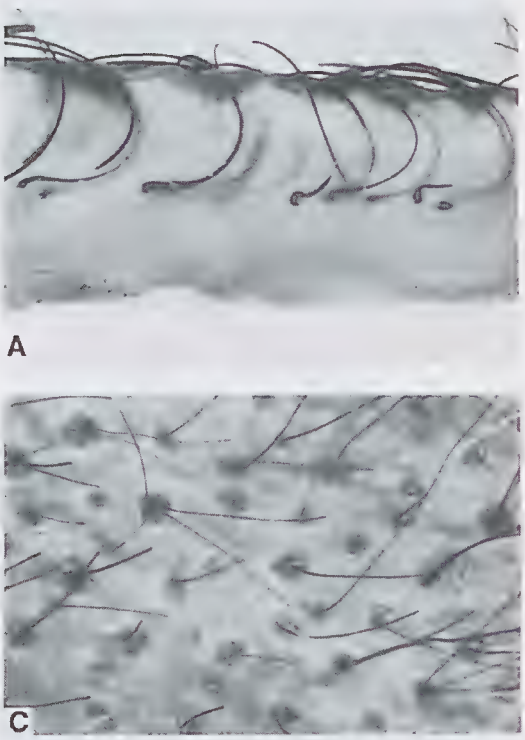

PLATE 9
Zulu: (A) scalp section; (B) scalp section; (C) scalp surface.

Zulu (Pl. 9 A–C)

Size
A mixture of diameters, but less variation than in Bantu.

Form
Follicle usually strongly curved, but some less so than others and tending to be straight; the curvatures all in the same direction, so that there is no crossing of the follicles.

Direction
Follicle meets surface of scalp at right angles; hair continues curvature of follicle.

Density
Average density less than in Bantu scalp, only one scalp showing the high density found there; follicles show no arrangement at origins, which are all deep; usual to find some arrangement of follicles at surface of scalp, with two, often three, hairs issuing together and on a small pigmented area; the hairs of these doublets and triplets may be of different diameters.

Bulb
Set at strong angle to shaft.

There are a few reports on the form of the follicle in the writings of others. Bloch & Vigier (1904) examined the follicles in a Negro of the Congo and found that they were strongly curved, that all lay in the same direction and that two, three and four hairs left the scalp together, so that there were bare areas on its surface. They also found that the hairs were usually elliptical and the individual hairs spiral. Their microscopic section shows that the bulb continued into the shaft of the follicle with a break in direction; and that the curvature of the follicle continued into that of the hair.

Turner (1914) published microscopic sections for the Negro and the Australian aboriginal. In the Negro the shaft was curved, but not markedly so, and the bulb was slightly angled to the shaft. The hairs lay in pairs deeply, one hair always larger than the other. At the surface the hairs emerged in pairs, sometimes three together and occasionally four. In the Australian aboriginal the shaft was straight and directed vertically or nearly so, and the bulb lay at a small angle to the shaft. The follicles reached the surface in groups of three, and the bulbs arose at different depths in the scalp.

DISCUSSION

Let us first consider the findings concerning hair form in relation to different peoples and the particular types found. Of the various measures of hair form, those of the cross-sectional dimensions have been the basis of most studies. Although it is usual to find a mixture of cross-sections among the hairs of the scalp, a particular form predominates in each. There are three main types: the circle, the oval ellipse and the flattened ellipse.

The only comprehensive report on the occurrence of these different forms in a wide range of peoples is that of Pruner-Bey (1865). He dealt with two features of the hair in his classification: one the hair index, that is, the relationship of the larger and smaller diameters of the hair, and the other

TABLE 2

Occurrence of the three main types of hair form*

	Index	Predominant form†
Circle		
Peru	0.98	Mostly round, some elongate (–)
Japan	0.96	Round (2)
Peru (mummy)	0.90	Nearly circular (–)
Mongol	0.88	Nearly circular (1)
Eskimo	0.85	Round to elliptic (2)
Siam	0.82	Round with some more elongate (–)
Choctaw Indian	0.80	Nearly circular, ranging to elongate (1)
Malay	0.74	Circular to oval (1)
Lithuania	0.74	Oval to circular (2)
China	0.72	Circular to elliptic (–)
Jamba	0.71	Circular to oval
Oval ellipse		
Western Pacific:		
New Caledonia	0.80	Oval elliptic (1)
New Zealand	0.73	Tendency to circular (3)
Australia	0.72	Oval elliptic (2)
Fiji	0.71	Elliptic (4)
New Ireland	0.69	Oval elliptic (4)
Tasmania	0.65	Oval elliptic (2)
Tikopia	0.68	Oval elliptic (2)
Nukahiva	0.61	Elliptic, tendency to circular (1)
Indian region:		
Kole	0.77	Most wide oval, tendency to circular (–)
Bhil	0.70	Oval to elliptic (–)
Gond	0.67	Mostly elliptic (–)
Persia	0.63	Oval elliptic (2)
Turk	0.62	Very elongate (1)
Brahman	0.61	Oval to elliptic (–)
North Africa:		
Algeria	0.88	Round to oval (1)
Berber	0.67	Oval to elliptic (1)
Egypt (mummy)	0.67	Mostly oval (6)
Arab	0.64	Elongate elliptic (1)
Egypt	0.54	Oval (most) to elliptic (2)
Europe:		
Basque	0.76	Circular–oval–elliptic (3)
Italy	0.75	Oval (–)
Irish (bog)	0.72	Oval to elliptic (1)
Germany	0.66	Oval (4)
Irish	0.66	Elliptic–oval–circular (47)
Flattened ellipse		
Negro	0.60	Elliptic (5)
Hottentot	0.55	Elliptic (narrow) (1)
Papua	0.42	Elliptic (2)

* From Pruner-Bey 1865.

† The figures in brackets are the numbers of scalps examined, a dash signifying that this is not stated.

a description of the hair of the scalp in terms of the predominant form present (see table 2).

There are some other records of hair index. Sergi (1957) reported values of 0.73 for Tasmanians and 0.57 for Bushmen. Neuert (1929, quoted by Sergi 1957) recorded values of 0.98 for Northern Manchuria, 0.79 and 0.82 for Chinese, 0.85 for Peruvians, 0.84 for Tamils, 0.81 for Fuegians and 0.75 for Aztecs. Turner (1914) refers to indices of 0.63, 0.67 and 0.68 for Tasmanians, 0.73 for New Hebrides, 0.70 for New Guinea, 0.51 and 0.53 for the Negro, 0.50 for the Hottentot, 0.52 for the Kaffir, 0.61 for the Andaman, 0.50 for the Semang of Malaya, 0.72 for Australian aborigines, and 0.85 for the Maori of New Zealand.

While sampling error and variability probably account for the differences between the measures for the same people, these differences do suggest that the hair index is not a reliable measure of the characteristic form of the hair in a particular people. Apparently more reliable are Pruner-Bey's descriptions of the predominant form.

Turner (1914) has drawn attention to another character which contributes to the predominant hair form found in a scalp, the twisting along the length of the hairs. The effect of this twisting differed with the length of shaft between the twists: it was shorter in the woolly hair of the Bushman than in the frizzy hair of the Tasmanians.

Probably relevant to the above is the comment of S.J. Hickson (quoted by Roth 1899) that "the curliness of the hair of the Tasmanians is less than that of any of the Papuans or Andamese, but more than that of the Australians. Thus the average diameter of the curl of the Andamese is 2 mm, of the Papuan 3 mm, of the Tasmanian 5 mm, but in the curliest hair of the Australians the curls are 10 mm in diameter and the average must be nearly 15 mm".

Another factor in the development of a characteristic hair form is the asymmetry in the deposition of pigment granules along the shaft. Thus, Spearman & Barnicot (1960) found that in the hair of the Negro of southern Nigeria, a greater density of pigment granules was to be seen on the concave side of the curl. They found the same in the Bantu, Bushman and Hottentot; also some indication of it in wavy European hair, but there was no asymmetry in the distribution of pigment in Chinese hair.

The wide variety of characters to be found in scalp hair of a particular form, a number of which have been mentioned in the above review, points to the futility of seeking a basic set upon which either to classify a predominant hair form or to explore human relationships in reference to it. It seems better to acknowledge that, because the hair is the end product of follicular activity, then any system of classification or means of comparing different peoples should be based on follicular characters.

During the development of the different isolates of humans, the genes concerned with the production of the hair have pursued different courses in the formation of isolates. One has only to point to the occurrence of a mutation in a Northern European family which has produced spiral hair (Schlaginhaufen 1945); not to mention the spiral form in the aborigines of Tasmania, who have been derived from an isolate of the people who occupied southeastern Australia about 10 000 years ago.

We have here a means of comparing populations by appropriate methods of statistical analysis. The characters of the follicle provide bases for study by such methods. To describe the follicle in a limited number of ways, as in this study, enables comparisons to be made.

It might be mentioned, by the way, that the present study provides a means of identifying a bare scalp in forensic examinations.

Two things have been demonstrated in our work, one that a particular human isolate can be characterised by the form of the hair follicle, and the other that similar hair forms can arise in different types of follicle.

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REFERENCES

Bloch, A. & Vigier, P., 1904. Recherches histologiques sur le follicule pileaux et le cheveu de deux Nègres décédés a Paris. *Bull. Mem. Soc. anthrop. Paris* 5(2): 124–132.

Plomley, N.J.B. & Baldwin, F., 1964. The hair follicle in the Tasmanian aborigines. Exhibit at meeting of Anatomical Society of Great Britain, Sydney, NSW, 5–6 February 1964.

Pruner-Bey, 1864. On human hair as a race-character, examined by the aid of the microscope. *Anthrop. Rev.* 2: 1–23.

Pruner-Bey, 1865. De la chevelure comme charactéristique des races humaines. *Mem. Soc. Anthrop. Paris* 2: 1–35, pls 1–3.

Roth, H. Ling, 1899. *THE ABORIGINES OF TASMANIA.* Halifax.

Schlaginhaufen, O., 1945. Helicotrichie in einem schweizerischen Stammbaum. *Arch. Julius Klaus-Stiftung* 20: 201–216, pls 1–10.

Sergi, S., 1957. Capelli di Tasmaniano e di Boscimanos. *Riv. Antrop. Roma* 44: 285–316, pls 1–10.

Spearman, R.I. & Barnicot, N.A., 1960. A study of the bilaterality of human hair. *Am. J. phys. Anthrop.* 18: 91–94, pl.1.

Trotter, M., 1938. A review of the classification of hair. *Am. J. phys. Anthrop.* 24: 105–126.

Turner, W., 1914. The aborigines of Tasmania. Part III. The hair of the head compared with that of other Ulotrichi and with Australians and Polynesians. *Trans. R. Soc. Edin.* 50: 309–347.

(accepted 9 August 1991)

OBSERVATIONS ON THE TASMANIAN MUDFISH, *GALAXIAS CLEAVERI* (PISCES: GALAXIIDAE)

by A.P. Andrews

(with two tables, one text-figure and two plates)

ANDREWS, A.P., 1991 (20:xii): Observation on the Tasmanian mudfish, *Galaxias cleaveri* (Pisces: Galaxiidae). *Pap. Proc. R. Soc. Tasm.* 125: 55–59. ISSN 0080–4703. Tasmanian Museum and Art Gallery, 40 Macquarie Street, Hobart, Tasmania, Australia 7000.

Meristic and morphometric comparisons are made of the three known populations of the Tasmanian mudfish; mainland Tasmania, Flinders Island and Victoria. The results of observations on the ecology and behaviour are reported.
Key Words: Tasmanian mudfish, taxonomy, ecology, behaviour.

INTRODUCTION

Most members of the genus *Galaxias* are small to medium-sized, fast-swimming, mid-water fishes that can be either lacustrine or diadromous (Whitley 1935). However, one species, *Galaxias cleaveri* Scott 1934, differs so markedly from typical Tasmanian members of the genus that at one stage it was referred to the genus *Saxilaga* by Scott (1936).

Meristic and morphometric comparison of the mainland Tasmanian, Flinders Island and Victorian populations indicate that the three are conspecific.

The principal non-taxonomic differences between *G. cleaveri* and other *Galaxias* are ecological and behavioural and the results of studies on these aspects of the species are reported here.

MATERIALS AND METHODS

The methods used to collect galaxiid fishes, as described in Andrews (1976), by the use of baited wire cage traps were unsuitable for *G. cleaveri* because of its benthic and secretive nature. However, since the species almost always occurs in small, discrete waterways, dip-netting was successful in most areas. Specimens for meristic and morphometric study were narcotised in the field with quinaldine and fixed in 10% formalin. After fixing, the specimens were transferred to 70% ethanol.

Ecological observations on *G. cleaveri* were made at Port Davey (southwestern Tasmania) at sites about 4 km south of Bathurst Harbour, in the Dover area (southeastern Tasmania), at sites near the mouth of the Esperance River, and in the Bridgewater area of the Derwent estuary, Hobart.

Observations on the behaviour of *G. cleaveri* and other species of *Galaxias* were made in the field and on specimens maintained live in aquaria for periods of up to six months. The aquaria were of all glass construction measuring 0.3 × 0.6 m and 0.4 m deep. In setting up the aquaria, every effort was made to duplicate as closely as possible the conditions under which the specimens were collected in the field. For *G. cleaveri*, the bottom of each tank was covered to a depth of 80–100 mm with sand, mud and coarse decaying vegetable material collected at the field sites and the tank was filled with water to a depth of 0.3–0.35 m.

No form of aeration was provided other than maintaining the aquaria in shaded, well-ventilated positions with the tops open to the air. Food consisted of live plankton and a proprietary flake food. This diet was supplemented occasionally with small pieces of finely chopped worms and crayfish.

TAXONOMY

The taxonomy of *G. cleaveri* has been considered (Andrews 1976) at both generic and specific levels, and subsequent authors, such as McDowall & Frankenberg (1981) and Jackson & Davies (1982), have neither made nor suggested any alterations. In 1976, *G. cleaveri* was known only from the Tasmanian mainland. The species has been subsequently recorded from two Victorian localities (Wilsons Promontory — Jackson & Davies 1982; Wye River, Otways — Koehn & O'Connor 1990), and from Flinders Island (Green 1984).

Meristic and morphometric comparisons of the three *G. cleaveri* populations were based on a series of 39 specimens from various Tasmanian localities and a series of six specimens in the collection of the Queen Victoria Museum and Art Gallery, Launceston (QVML No 1984/5/6), collected from Patriarchs Reserve, Flinders Island, grid reference FR020750. The ten specimens from Wilsons Promontory, now in the Museum of Victoria, Melbourne (MOV No A2037), were also examined.

Measurements and counts made follow Andrews (1976), except that all segmented rays, branched and unbranched, were counted in the dorsal and anal fins.

The meristic and morphometric data for the three *G. cleaveri* populations are given in tables 1 and 2. Jackson & Davies (1982) concluded that the Victorian and Tasmanian populations were conspecific, using data from Andrews (1976) for the Tasmanian *G. cleaveri*. The results of the present study confirm their findings and indicate that the Flinders Island population is also conspecific with these populations.

The meristic data indicate a slight tendency towards fewer anal and ventral rays in the Flinders Island specimens but the differences are small and the ranges of the Flinders Island and Victorian specimens are within the range of the Tasmanian specimens. The morphometric data indicates a longer and narrower caudal peduncle in the Victorian population and a tendency towards longer paired fins, shorter jaws and narrower heads. Again, however, these differences are small and the possible reasons for such variations are discussed elsewhere.

TABLE 1
Meristic variation in *G. cleaveri*

	Dorsal rays						Anal rays						Pectoral rays					Ventral rays			
	9	10	11	12	13	SD	11	12	13	14	15	SD	12	13	14	15	SD	5	6	7	SD
Tasmania	2	3	13	16	5	0.97	6	6	13	12	2	1.13	2	24	12	1	0.36	2	11	26	0.28
Flinders Is	1	2	2	1		1.25	5	1				0.37	2	4			0.30	1	5		0.12
Victoria	1	2	5	2		0.44	2	6	2			0.45		8	2		0.17		2	8	0.17

TABLE 2
Morphometric variation in *G. cleaveri**

Parameters†	Tasmania				Flinders Island				Victoria			
	Min	Mean	Max	S D	Min	Mean	Max	S D	Min	Mean	Max	S D
Head/LS	19.0	20.4	22.8	1.05	18.5	19.2	21.0	0.70	20.3	21.2	22.0	0.59
S–DO/LS	72.4	74.6	78.7	1.80	68.3	73.5	77.5	3.20	69.0	71.3	74.8	1.64
S–VO.LS	50.6	53.3	57.8	2.29	50.2	52.5	56.5	2.00	49.3	51.9	54.6	1.51
PL/PB–VO	31.5	35.6	42.0	3.25	31.0	35.4	37.6	2.20	34.3	39.1	43.4	2.77
VL/VB–AO	34.0	39.1	46.4	3.85	32.4	38.1	46.3	4.60	38.7	42.2	45.4	2.08
DCP/LCP	62.5	71.3	81.0	7.33	58.3	77.0	91.6	11.40	42.0	50.7	56.7	4.32
LCP/LS	10.8	11.9	13.4	0.85	9.9	11.2	12.3	0.80	15.7	17.1	18.3	0.89
ED/HL	8.0	11.3	14.0	1.75	11.4	12.1	12.4	0.80	10.9	13.2	15.0	1.21
UJL/HL	22.6	27.5	31.4	2.62	25.6	29.7	31.7	2.30	23.2	24.8	27.1	1.25
LJL/HL	23.1	28.3	32.0	2.74	28.1	32.6	36.5	3.10	21.9	25.0	28.4	1.95
GW/HL	28.1	35.9	42.8	3.70	35.5	39.2	44.5	2.90	27.7	32.0	39.3	4.02
IW/HL	33.9	36.7	39.1	1.70	35.5	38.1	41.3	2.10	35.8	40.2	45.1	2.97
HW/HL	48.1	61.4	68.4	6.20	59.5	66.0	74.8	4.90	52.2	58.1	65.8	5.21

*Numerator written as a percentage of the denominator
† Abbreviations used are as follows: LS standard length (snout tip to hypural joint), HL head length (snout tip to posterior edge of opercular flap), S–DO snout tip to dorsal fin origin, S–VO snout tip to ventral fin origin, PL pectoral fin length, PB–VO pectoral fin base to ventral fin origin, VL ventral fin length, VB–AO ventral fin base to anal fin origin, DCP minimum depth of caudal peduncle, LCP dorsal length of caudal peduncle, ED eye diameter, UJL upper jaw length, LJL lower jaw length, GW gape width, IW interorbital width, HW head width.

DISTRIBUTION AND ECOLOGY

The presently known distribution of *G. cleaveri* is illustrated in figure 1, which includes data from Andrews (1976), McDowall & Frankenberg (1981), Jackson & Davies (1982) and Koehn & O'Connor (1990), together with the results of the present study.

In comparison with the distributions of some of the diadromous species such as *Galaxias maculatus* and *G. truttaceus*, as recorded by McDowall & Frankenberg (1981), *G. cleaveri* is fairly restricted. However, it is far less restricted than some of the lacustrine species, such as *G. johnstoni*, which are often confined to a single body of water (Andrews 1985).

The preferred habitat of *G. cleaveri* is in low-lying coastal areas, virtually at sea level. The species appears unable to invade inland and upland waterways, and during the present study only two collection sites were recorded at any marked distance from the coast (fig. 1). These two sites, in the Derwent and Tamar estuaries, consisted of small stagnant anabranches of streams flowing into the rivers at points well within the tidal limits.

At no time during the present study were adult *G. cleaveri* either observed or collected in free-running water; the usual sites were small pools up to 2 m in diameter and 0.5 m deep.

Most of the observations on *G. cleaveri* in the field were made at Port Davey, southwestern Tasmania. The study area consisted of a flat alluvial flood plain, about 4 km south of Bathurst Harbour, grid reference DM320920 (pl. 1). The plain is sparsely vegetated with low (1 m high) shrubs and buttongrass (*Gymnoschoenus* sp.), and is drained by a number of small streams which flow north into Melaleuca Lagoon. Significant deposits of alluvial tin (cassiterite) occur in the area and these have been mined from the mid 1940s until recent years. The deposits are in the form of lens-shaped pockets of ore located 0.5–3.0 m below the surface.

The ore pockets were located by the mining leaseholder by digging rectangular test holes approximately 1.0 m square by 0.5–1.0 m deep (pl. 2). These test holes were invariably filled with ground water which was stained a dark brown with humus and formed an ideal habitat for *G. cleaveri*.

Specimens were collected from the holes by dip-netting, each hole yielding two, sometimes three or four *G. cleaveri*, usually within the standard length range 70–80 mm, but juveniles about 25–30 mm were also taken.

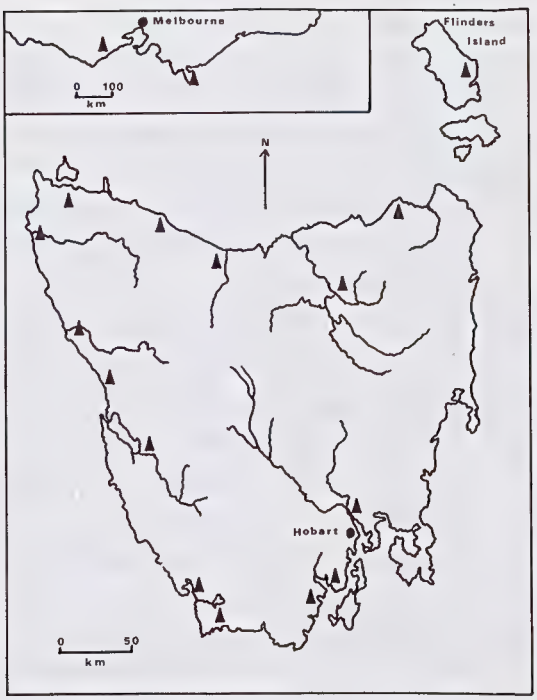

FIG. 1 — Distribution of Galaxias cleaveri *(inset: Victoria).*

PLATE 1
Typical habitat of Galaxias cleaveri, *Port Davey.*

PLATE 2
Pond containing Galaxias cleaveri, *Port Davey.*

The small surface streams which crossed the plain in places (pl. 1) were also sampled for *G. cleaveri.* None were collected but a few post-larval specimens of *G. maculatus* were occasionally found.

Two of the test holes were emptied by pumping out the water and straining the bottom sediment with a net. This consisted of a dark-brown layer of decaying plant material some 100–150 mm thick, liberally mixed with coarse quartzite sand. The water was acidic with pH values of 5.0–5.5 being recorded. Microscopic examination of the sediment revealed numerous insect remains, but these were too fragmented for species to be determined.

For comparative purposes, fish trapping was carried out in nearby Moth Creek using the methods described in Andrews (1976). Abundant adult *G. maculatus* and *G. truttaceus* were recorded but no *G. cleaveri,* despite trapping over several days.

In the Dover and Bridgewater areas, *G. cleaveri* was found in stagnant pools in non-running stream beds and roadside drainage ditches. In these localities, the water was 0.25 m or less in depth and the substrate consisted of black mud and decaying vegetable material. At one of the Dover localities the water was often covered with a metallic film, a phenomenon also recorded by Jackson and Davies (1982), who attributed it to the presence of metallic sulphides formed under anaerobic conditions.

The habitat of *G. cleaveri* on Flinders Island and southern Victoria is essentially the same as that in Tasmania. The Flinders Island specimens were taken from a drain leading to landlocked lagoons and a marsh in Patriarchs Reserve, some 2 km from the sea. On Wilsons Promontory, where the Victorian specimens were collected, the habitat was described by Jackson and Davies (1982) as a small, swampy tributary of Freshwater Creek on the southeastern side of the promontory. There was no discernable flow, the mean depth was 0.16 m and the substrate was composed of mud.

The feeding and life history of *G. cleaveri* were discussed in Andrews (1976), but it was not known if the life cycle included a marine juvenile stage. Juveniles were collected at Trial Harbour, on the west coast, from a small pond at the outfall of a stream flowing across the beach about 1.0 m from the high tide level. The pond contained black peaty sediment and water that was strongly saline to the taste. It was concluded from this that juvenile *G. cleaveri* were salt tolerant.

McDowall (1980) and McDowall & Frankenberg (1981) reported that the entire life cycle was spent in fresh water. More recently, however, Fulton (1986) identified juvenile *G. cleaveri* in runs of whitebait, *Lovettia sealii,* caught in a number of rivers around the state.

It seems likely, however, that other Tasmanian populations are confined entirely to fresh water. At Port Davey, many of the pools containing *G. cleaveri* were completely surrounded by dense grass and undergrowth, with no aquatic connections to other bodies of water. The pond shown in plate 2 is one such example, with the nearest running water some 8.0 m distant. In such cases, both juvenile and adult *G. cleaveri* were collected from the same pond.

A specimen in the Tasmanian Museum, No D1235, was one of several collected from small cavities in a 0.3 m layer

of damp mud and sediment being removed from an empty farm dam at Huonville by a bulldozer. On being returned to water, all the fish began swimming normally without showing any signs of stress or dehydration. The dam was located about 0.75 km from the nearest running water.

It seems, therefore, that, in common with several other galaxiid species in Tasmania, notably *Galaxias brevipinnis*, the marine juvenile stage is facultative rather than obligatory in *G. cleaveri*.

The ability of *G. cleaveri* to survive dry periods by burrowing in damp mud has been noted by a number of authors, most recently by Fulton (1986). Hall (1901) described a fish he identified as *Galaxias* sp. being dug up at Strahan in decayed peat and sand 20 mm below the surface. From Hall's brief description it is likely that the fish was *G. cleaveri*. Scott (1934), in his original description of the species, noted that his specimen had been found in a damp hollow in a rotten log.

Unlike other members of the genus, *G. cleaveri* appears tolerant of quite wide variations in temperature. During the summer of 1978, a field trip to the Dover area yielded adult examples of both *G. cleaveri* and *G. maculatus*. The specimens were placed in a black polythene 50 litre drum, which was left open at the top. However, during the return journey the vehicle in which the fish were transported was inadvertantly left parked in direct sunlight for several hours. Although the rise in the water temperature was estimated at not more than 3-4°C at the most, it proved fatal to the *G. maculatus* but the *G. cleaveri* showed no signs of distress.

Both the Dover and Bridgewater collecting areas are subject to frost and, during severe winter conditions, the ponds from which *G. cleaveri* had been collected would occasionally ice over. By contrast, these ponds, being very shallow, can heat up quickly when exposed to direct summer sunlight. Virtually all those examined in the Dover and Bridgewater areas were devoid of any shade cover, and early afternoon water temperatures as high as 19°C were recorded during the study.

BEHAVIOUR

The only comparable studies of galaxiid fishes in aquaria appear to be those of Davidson (1951) and Eldon (1969). Davidson kept the New Zealand brown mudfish, *Neochanna apoda*, in aquaria with varied success, while Eldon maintained various New Zealand species of *Galaxias* in aquaria, including the brown mudfish. Eldon (1969) also reported on the keeping of the black mudfish, *Neochanna diversus*, in aquaria, again with varied success.

According to McDowall (1970), *G. cleaveri* and the three New Zealand species of *Neochanna* are counterparts, possibly phylogenetically related, and share similar ecological niches.

Typical members of the genus *Galaxias*, such as *G. maculatus* and *G. truttaceus*, are shoaling mid-water species. When placed in aquaria, they confined most of their activities to the middle and upper third of the water column. They rarely surfaced but often foraged on the bottom, picking up and ejecting mouthfuls of sand. When light food particles were placed on top of the water, however, the fish fed rapidly with quick darting movements, often breaking the surface.

Locomotion is by lateral oscillation of the tail and that part of the body posterior to the ventral fins. Rapid oscillation, to increase the speed, is usually done in short bursts with breaks in between, resulting in a fast darting movement. When at rest, the mid-water position is maintained by a gentle undulating movement of the vertical fins and occasional stabilising movements of the paired fins.

The shoaling behaviour of both *G. maculatus* and *G. truttaceus* became evident when two or more specimens were placed in the same aquarium. After a while, individual fish grouped closely together and moved as a co-ordinated unit. Occasionally, members of the group would separate for short periods in order to forage or carry out some activity of their own.

By contrast, *G. cleaveri* is benthic, solitary and sedentary. When first placed in the aquarium, the fish immediately swam to the bottom and remained partially, and sometimes completely buried in the sediment. If undisturbed, they remained in this position for up to 4–5 hours at a time, occasionally making short exploratory trips to other parts of the aquarium. Once acclimatised, specimens spent most of the time motionless on the bottom, often partially submerged in the sediment.

Occasionally, individuals were observed burrowing vigorously through the sediment, stirring up large quantities as though searching for food.

No difficulty was experienced with acclimatising adult *G. cleaveri* to aquarium life, and a similar situation was found by Eldon (1969) with adults of the New Zealand brown mudfish, *Neochanna apoda*.

Locomotion in *G. cleaveri* differs markedly from that in other members of the genus. When specimens on the bottom of the aquarium were suddenly disturbed, they swam rapidly and vertically to the surface, often emerging completely from the water to a height of 50–60 mm and immediately diving back to the bottom. This manoeuvre would be repeated two or three times in quick succession before the fish again buried themselves in the sediment.

This aspect of the behaviour of *G. cleaveri* could be used to advantage when collecting specimens in the field. Ponds suspected of containing *G. cleaveri* were agitated vigorously for a second or two with a pole to disturb the bottom. Simultaneously, a long-handled dip-net was swept through the water to collect the fish.

The swimming method observed in *G. cleaveri* was an undulating, eel-like motion, the undulations commencing at the head and extending over the entire length of the body. This method was used for both horizontal and vertical swimming as well as burrowing, with little, if any, use being made of the paired and vertical fins.

No evidence of shoaling or other social behaviour was observed in *G. cleaveri*. When two or more individuals were placed in the same aquarium, they remained apart and gave no indication of being aware of each other's presence. When chance meetings occurred, such as bumping into each other while foraging, they immediately resumed their former activities, apparently regarding each other with complete indifference. By contrast, Eldon (1969) found that, when two or more specimens of the New Zealand mudfish, *Neochanna apoda*, were placed in an aquarium, they spent the daylight hours under cover on the bottom, packed together in close physical contact.

Both Davidson (1951) and Eldon (1969) reported instances of aggressive behaviour in *Neochanna apoda*, but no such behaviour was observed during the present study, either between individual *G. cleaveri* or with other species.

DISCUSSION AND CONCLUSIONS

Most Australian members of the genus *Galaxias* are agile, fast-swimming fishes which typically inhabit cool, clear, well-oxygenated water. By contrast, *G. cleaveri* has adapted to an environment which virtually all other members of the genus would find intolerable. Adaptations include the ability to remain dormant for long periods and to tolerate low oxygen levels, both indicative of a very low metabolic rate and probably a fairly modest food requirement. Jackson & Davies (1982) collected *G. cleaveri* from water which they reported as having no measurable dissolved oxygen. These adaptations undoubtedly account for the ability of *G. cleaveri* to aestivate in damp mud and sediment in the absence of free water.

As noted previously, *G. cleaveri* can tolerate wide, and often sudden fluctuations in temperature that are lethal to other *Galaxias*. This ability is obviously essential for a fish which inhabits small, shallow ponds that are exposed to direct sunlight.

In comparison to the lacustrine and fluviatile *Galaxias*, the ecological niche occupied by *G. cleaveri* seems to be rather a precarious one. However, an advantage could well be that, when the ponds dry up, forcing the fish to aestivate, the refilling after rain often results in a hatching of insects and other aquatic fauna. This would provide a readily accessible food supply, completely free from competition with other fish species.

The results of the meristic and morphometric comparisons undertaken in the present study indicate that the three populations discussed are all clearly referrable to *G. cleaveri*. The small differences that exist between them are undoubtedly due to the effects of geographic and genetic isolation and, perhaps, the influence of environmental factors. These aspects of freshwater fish populations have been discussed in detail by McDowall (1972).

More detailed statistical comparison of the three populations was not made for two reasons, viz. the small size of the Flinders Island sample in comparison with the Tasmanian sample, and the fact that all six Flinders Island specimens were large, gravid females with distorted body shapes which would have made such comparisons meaningless.

With the extension of the known range of *G. cleaveri* to Flinders Island and Victoria, the distribution now resembles that of another galaxiid species, *Galaxiella pusilla* (Mack) (Andrews 1976, McDowall & Frankenberg 1981).

However, whereas *G. cleaveri* is quite widespread in Tasmania, *Galaxiella pusilla* is restricted to a few areas in the northeast of the state.

Although in separate genera, these two species share somewhat similar ecological niches. Both are sedentary, limited in range and confined to low-lying coastal areas. Both species also favour small, stagnant water bodies, *Galaxiella pusilla* thriving in those with weed growth and algae.

Andrews (1976) explained the distribution of *Galaxiella pusilla* by the hypothesis that the species may have been distributed widely over southeastern Australian coastal areas but that the three present populations became isolated by the formation of Bass Strait some 8000–10 000 years ago, at the end of the Quaternary Period.

The results of the present study lead to the suggestion that the distribution of *G. cleaveri* can also be explained by the same hypothesis.

ACKNOWLEDGEMENTS

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REFERENCES

ANDREWS, A.P., 1976: A revision of the Family Galaxiidae (Pisces) in Tasmania. *Aust. J. Mar. Freshw. Res.* 27: 297–349.

ANDREWS, A.P., 1985: A new species of *Galaxias* (Pisces: Galaxiidae) from southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 119: 55–60.

DAVIDSON, M.M., 1951: The New Zealand mudfish (*Neochanna apoda*). *NZ Aquarium Bull.* 12: 33.

ELDON, G.A., 1969: Observations on growth and behaviour of galaxiidae in aquariums. *Tuatara* 17(1): 34–46.

FULTON, W., 1986: The Tasmanian mudfish *Galaxias cleaveri* Scott. *Fishes of Sahul* 4(1): 150–151.

GREEN, R.H., 1984: The Tasmanian mudfish on Flinders Island. *Tasm. Nat.* 77: 7.

HALL, T.S., 1901: A burrowing fish (*Galaxias* sp.). *Vict. Nat.* 18: 65–66.

JACKSON, P.D. & DAVIES, J.N., 1982: Occurrence of the Tasmanian mudfish, *Galaxias cleaveri* Scott, on Wilsons Promontory — first record from mainland Australia. *Proc. R. Soc. Vict.* 94 (1): 49–52.

KOEHN, J.D. & O'CONNOR, W.G., 1990: Distribution of freshwater fish in the Otway region, south-western Victoria. *Proc. R. Soc. Vict.* 102: 29–39.

MCDOWALL, R.M., 1970: The galaxiid fishes of New Zealand. *Bull. Mus. Comp. Zool. Harv. Univ.* 139: 341–431.

MCDOWALL, R.M., 1972: The species problem in freshwater fishes and the taxonomy of diadromous and lacustrine populations of *Galaxias maculatus* (Jenyns). *J. R. Soc. NZ* 2 (3): 325–367.

MCDOWALL, R.M., 1980: Family Galaxiidae. *In* McDowall, R.M. (Eds): *FRESHWATER FISHES OF SOUTH-EASTERN AUSTRALIA*. A.H. and A.W. Reed, Sydney: 55–69

MCDOWALL, R.M. & FRANKENBERG, R.S., 1981: The galaxiid fishes of Australia. *Rec. Aust. Mus.* 33 (10): 443–605.

SCOTT, E.O.G., 1934: Observations on some Tasmanian fishes with descriptions of new species. *Pap. Proc. R. Soc. Tasmania* (1933): 31–53.

SCOTT, E.O.G., 1936: Observations of fishes of the family Galaxiidae. Part 1. *Pap. Proc. R. Soc. Tasm.* (1935): 83–112.

WHITLEY, G.P., 1935: Whitebait. *Vict. Nat.* 52: 41–55.

(accepted 3 May 1991)

SEASONAL CHANGES IN HYDROLOGY AND THE DISTRIBUTION OF PLANKTON IN THE BATHURST HARBOUR ESTUARY, SOUTHWESTERN TASMANIA, 1988–89

by G. J. Edgar and G. R. Cresswell

(with two tables and eleven text-figures)

EDGAR, G.J. & CRESSWELL, G.R., 1991 (20:xii): Seasonal changes in hydrology and the distribution of plankton in the Bathurst Harbour estuary, southwestern Tasmania, 1988–89. *Pap. Proc. R. Soc. Tasm.* 125: 61–72. ISSN 0080–4703. Zoology Department, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001 (GJE); CSIRO Division of Oceanography, Marine Laboratories, GPO Box 1538, Hobart, Tasmania, Australia 7001 (GRC).

The hydrology and abundance of planktonic organisms (>20 μm size) were surveyed at various sites in the Bathurst Harbour/Port Davey estuary on five occasions between October 1988 and July 1989, and the hydrology again surveyed in February 1991. In winter, the period of peak freshwater outflow, a brackish surface layer (≈15‰) was present to a depth of ≈4 m throughout the estuary. This surface layer was present to a reduced depth in other seasons, except during summer, when the halocline broke down and surface salinities of ≈29‰ in 1989 and ≈25‰ in 1991 prevailed. Bottom waters were close to fully marine (≈33‰) throughout the year. Surface waters in Bathurst Harbour were found to be extremely depleted in nitrates (<0.1 μM). Oxygen levels were also very low (≈35% saturation) during the 1989 summer, which was unusually dry, but were near full saturation during the other sampling periods.

The plankton community in Bathurst Harbour contained very few taxa, particularly during the winter months. The dinoflagellate *Dinophysis acuminata* comprised >99% of total phytoplankton numbers in October 1988 and July 1989, while the copepods *Gladioferens inermis* and *Oithona australis* and the appendicularian *Oikopleura* sp. numerically dominated the zooplankton community. Dinoflagellates and copepods both occurred in high densities. The distribution of diatoms within the estuary was inversely related to the distribution of dinoflagellates; diatoms occurred in low densities relative to dinoflagellates in Bathurst Harbour outside the summer months, but occurred in much higher densities than dinoflagellates in the waters of Port Davey throughout the year.

Key Words: Bathurst Harbour, Port Davey, estuary, hydrology, salinity, temperature, oxygen saturation, nitrate concentration, phytoplankton, zooplankton, *Gladioferens inermis*, *Dinophysis acuminata*, *Oithona australis*, Tasmania.

INTRODUCTION

A single large sheltered inlet, Port Davey, is present along the 250 km section of Tasmanian coast between Macquarie Harbour on the western coast and Recherche Bay on the southeastern coast. This inlet was formed by a marine transgression into the lower reaches of the principal rivers of the region, the Davey and Old Rivers. The Old River empties into Bathurst Harbour, which is connected to Port Davey via Bathurst Channel. Several other river systems, notably the Spring and North Rivers, also feed into Bathurst Harbour and Bathurst Channel.

The Port Davey/Bathurst Harbour estuarine system differs from others in southern Australia because it is the only large estuary fed by unrestrained rivers, without road access, and without significant human impact (except, perhaps, for landscape modification due to increased fire frequency and two small tin leases operated beside Moth Creek near Melaleuca Inlet). The permanent population within the 2000 km^2 catchment area consists of two tin miners, with a transient population of fishermen, bushwalkers, sailors and airborne tourists reaching a daily maximum of ≈100 during summer.

Because of the isolation of the area, nothing was known of the hydrology of Port Davey or the Bathurst Harbour estuary (defined in this study as including Bathurst Harbour and associated estuarine inlets, Bathurst Channel, and the section of Port Davey east of Breaksea Island), other than that the surface waters were highly stained by tannins and that the freshwater entering the system had an ionic composition similar to seawater (Buckney & Tyler 1973) before 1977. In that year, the Tasmanian Government commissioned the South West Tasmania Resources Survey, and, as part of this, two hydrological surveys were conducted in the region, the first between 31 December 1977 and 6 January 1978 (Thomson 1978a) and the second from 16 to 20 July 1978 (Thomson 1978b). During both surveys, water temperature, salinity, pH and dissolved oxygen concentrations were measured at one to three depths at a number of stations in Kelly Basin, Port Davey, Bathurst Channel, Bathurst Harbour and Melaleuca Inlet. Thomson (1978a,b) found during his surveys that Port Davey and Bathurst Harbour were more marine than previously anticipated, and that Bathurst Harbour and Bathurst Channel were highly stratified, with a brackish layer overlying marine waters which extended to a depth of 4 m in winter but to only 2 m in summer.

Virtually nothing was known about the planktonic assemblages within the estuary prior to the present study; the only effort to collect plankton from the Bathurst Harbour estuary was made by the Biological Society of the University of Tasmania, during a summer 1969 field trip. The Biological Society collected an unusual cyclopoid copepod from the western outlet of Bathurst Channel but was unsuccessful in attempts to collect plankton from sites further upstream (Ong 1969); they consequently concluded that the estuary has a negligible abundance of plankton. This absence of studies in Bathurst Harbour and Bathurst Channel contrasts with the considerable information available on the plankton communities in the Derwent and Huon River estuaries (Nyan Taw & Ritz 1978, 1979; Ong 1967), the two other large estuaries in southern Tasmania.

The hydrological and plankton investigations described here were partly intended to extend Thomson's hydrological

results and provide a preliminary account of near-surface (< 1m) zooplankton and phytoplankton within the Bathurst Harbour estuary. A more important function of these surveys was to form part of a larger study aimed at quantifying seasonal changes in the major physico-chemical and biological features of the estuarine ecosystem. Information on the mobile benthic fauna and fish in the Bathurst Harbour estuary is presented in associated papers (Edgar 1991a,b). Such information is particularly important for the optimal management of the region because the data provides a baseline against which any future changes can be compared. The study also provides unique information for southern Australia on the natural, pre-anthropogenically disturbed state of a large estuary.

METHODS

Area Investigated

The Bathurst Harbour estuary contains three major geographical components (fig. 1): a section of a coastal embayment (Port Davey), a sheltered estuarine basin (Bathurst Harbour), and the heavily indented connecting passage. This passage, Bathurst Channel, is approximately 1 km wide and traverses 12 km through quartzitic hills. It superficially resembles a fjord, and was initially considered as one; however, it is now recognised as a drowned river valley of the trellis type (Baker & Ahmad 1959). Hydrographic charts of the area (Australian Admiralty Charts AUS 175 and AUS 176) surveyed in 1922 indicate that the bottom of Bathurst Channel varies from 15 to 40 m depth, but that a relatively shallow sill (≈12 m) at its western end separates the channel from the deeper waters of Port Davey and the open sea. At its eastern end, Bathurst Channel forms the outlet for Bathurst Harbour, a large (≈7 km long, ≈5 km wide) basin, surrounded on all sides by hills. The floor of Bathurst Harbour is flat, rising gradually from 7 m deep in the eastern sector to slightly shallower depths (6 m) near its western outlet (Australian Admiralty Chart AUS 176). The area was probably once a large buttongrass plain which became inundated by marine water, following recent sea level rises.

Hydrology

Hydrological data were collected on six occasions between 8 October 1988 and 23 February 1991, at ten stations along a transect running from the mouth of the Old River in Bathurst Harbour to the western side of Breaksea Island in Port Davey, and at five stations along a transect running along Melaleuca Inlet from the Boat Landing in Melaleuca Lagoon to Celery Top Island (fig. 1). Additional hydrological data were collected from three sites along the Old River (First Bend, Old River 8111 Tasmap grid reference DN374024; Huon Pines, DN378032; Islet, DN386037) on 27 November 1988 and 25 July 1989, and four sites on the Davey River (Carvers Point Shoal, Port Davey 8011 Tasmap grid reference DN130135; Settlement Point, DN118150; Foot Track Islet, DN122204; Davey Gorge, DN132212) on 12 February 1989. At each station salinities and water temperatures were recorded using a Hamon Salinometer at 1 m intervals for the first 10 m below the water surface and then at 2 m intervals to the bottom. Dissolved oxygen concentrations (measured using a Yeocal O_2-meter) and light levels (PAR measured with a Licor photometer) were also measured on 23 February

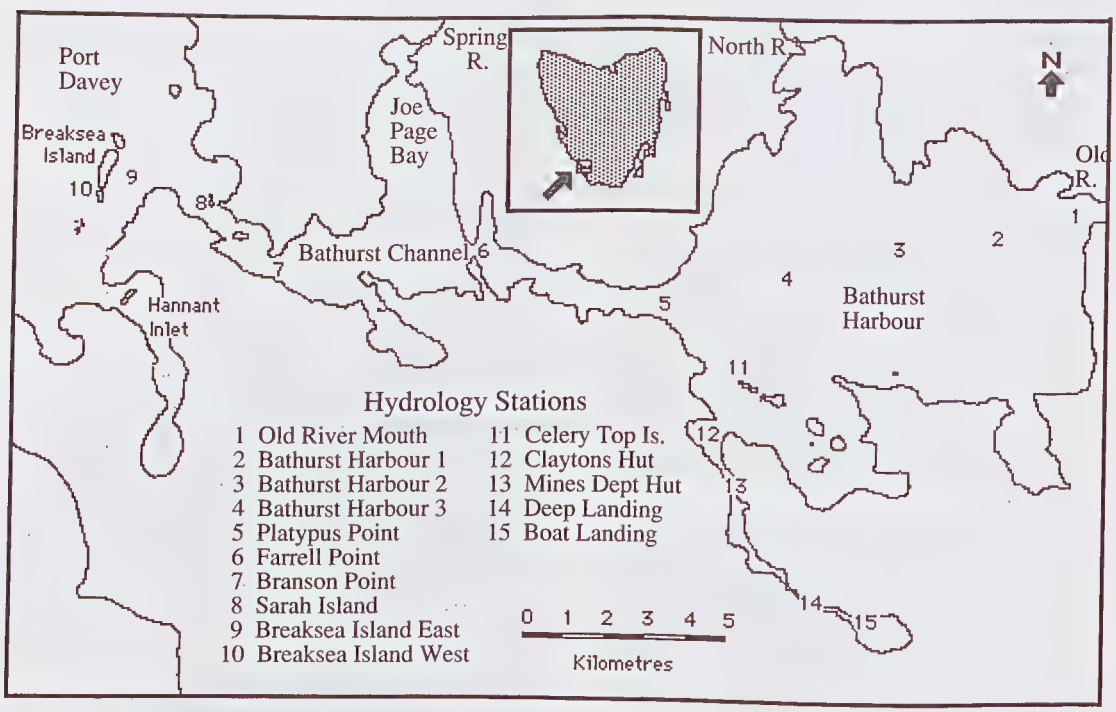

FIG. 1 — Hydrological stations surveyed during the study.

1991 at these sites and depths. Water samples were collected for nitrate analysis at Stations 1 (Old River Mouth), 3 (Bathurst Harbour 2), 5 (Platypus Point), 6 (Farrell Point), 8 (Sarah Island) and 9 (Breaksea Island East). At these stations a Niskin bottle was triggered at depths of 0, 2 and 0.5 m above the bottom, and at 4 and 6 m if water depths allowed. The sample was then retrieved and preserved, using $HgCl_2$ for analysis of NO_2^- and $NO_2^-+NO_3^-$ in the laboratory with a Technicon AutoAnalyser (Department of the Environment). Water samples were also collected at various depths and seasons from Stations 1, 3, 5 and 8 for oxygen and salinity analysis, using the laboratory methods of Major *et al.* (1972). Oxygen samples were transferred from the Niskin to a BOD bottle on the boat, fixed immediately by the addition of $MnSO_4$, KI–KOH and H_2SO_4, and stored in the dark. The laboratory salinity measurements were used to calibrate the *in situ* salinity data.

Hydrological data obtained during the study should encompass normal seasonal extremes within the estuary; one survey (8 October 1988) was conducted during a month of exceptionally high rainfall, the wettest month on record at Melaleuca, while another (8 February 1989) was conducted during the middle of a dry summer (D. King, meteorological records).

Plankton

Plankton samples were collected using a 220 mm diameter, 20 µm mesh plankton net which was slowly towed at ≈0.3 m depth behind a runabout dingy for 120 s intervals. Collections were made at most of the stations at which hydrological data were collected (fig. 1) along the transect from Bathurst Harbour to Port Davey: Stations 3 (central Bathurst Harbour), 5 (Platypus Point), 6 (Farrell Point), 7 (Branson Point), 8 (Sarah Island), 9 (Breaksea Island East) and 10 (Breaksea Island West). Two replicate samples were collected at each site during the December, February, May and July surveys, with unreplicated samples being made on 8 October 1988 and no sample being collected off Branson Point on that date. Once each sample was collected and the 50 ml sample bottle unscrewed from the net, the contents were preserved by adding buffered formalin (≈2% v/v). A General Oceanics Model 2030 Digital Flowmeter, which was fitted into the mouth of the net during the 25 July 1989 survey, indicated that the mean velocity of water passing through the centre of the net was 0.115 m/s, hence the net filtered ≈0.5 m^3 of water during each 120 s sampling period.

In the laboratory, two 0.3 ml aliquots from each sample were placed under cover slips on separate microscope slides, and the abundances of planktonic taxa recorded while scanning four times across the slides using the 10× objective of a compound microscope. Whenever the number of zooplanktonic organisms was low (i.e. <50 animals were recorded during the scanning of a slide), the zooplankton in the primary sample was also sorted and counted under a dissecting microscope. Plankton counts on microscope slides were converted to total sample counts by multiplying by a factor of 182; the regression $P = 182 \times S$ ($n = 11$, $r^2 = 0.80$) was calculated from the December data, where P is the zooplankton abundance recorded from a sample by direct count and S is the number of zooplankton taxa recorded during a total of eight traverses across the two slides from each sample. The biomass of zooplankton in each sample was determined by rinsing a 10% v./v. subsample in freshwater, passing it through a 0.52 µm Millepore filter and then calculating the difference between the predried and postdried (at 60 °C for 2 hours) weight of the filter plus animals.

Our study of the distribution of planktonic plants and animals within the Bathurst Harbour estuary was not aimed at the total planktonic community; organisms below 1 m depth or smaller than 20 µm mesh size were not collected. The nanoplankton (2–20 µm) and picoplankton (0.5–2 µm) communities in Bathurst Harbour consequently remain unstudied, while larger fragile flagellates were probably also underrepresented in formalin-preserved samples. It should also be noted that the abundance data, as shown in the various figures, may have been systematically underestimated because (i) the sampling vials attached to the net did not have drainage windows, hence the net could not be washed down and some water with organisms was lost when the sampling vials were unscrewed; and (ii) calculations of the water sieved through the net were based on water passing through the centre of the net, with the reduction in water flow due to drag near the edges of the net not being accounted for. Any errors should, however, be constant for different sites and sampling periods, hence the numerical data can be confidently compared between sites and seasons.

RESULTS

Hydrology

Temperature, salinity and nitrate sections in the upper 8 m along the axis of Bathurst Harbour estuary for the various seasonal surveys are shown in figures 2, 3 and 4. The sections are complemented by the temperature and salinity data (fig. 5) for sites representative of Bathurst Harbour (Bathurst Station 2) and the deep part of Bathurst Channel (Branson Station), which are presented as depth profiles of temperature and salinity. Figure 6 includes the corresponding data for a station representative of the deep part of Macquarie Harbour (from Cresswell *et al.* 1989). The Bathurst and Macquarie systems will be compared later in this paper.

Water temperatures (fig. 2) varied more in Bathurst Harbour than at the western outlet of Bathurst Channel, presumably because of the large expanse of shallow water in Bathurst Harbour, the highly variable riverine input, and the buffering provided by seawater near the outlet.

Waters in Bathurst Harbour below 5 m depth (figs 2 and 5) varied only between 12° and 14°C during the spring, autumn and winter sampling surveys, and increased to ≈17°C during summer. Maximum–minimum thermometers indicated, however, that the annual temperature range (≈10–19°C) for water at 8 m depth (table 1) was greater than that recorded during the surveys.

The deep part of Bathurst Channel, represented by the Branson Station in fig. 5, showed only a 1.5°C temperature range at 30 m depth. At the surface, however, the temperatures over the various surveys ranged over 10°C, being ≈3°C cooler than the bottom waters in winter and ≈6°C warmer in February 1989.

On most surveys, a well-defined halocline was present in the top 6 m, gradually decreasing in depth from Bathurst Harbour to the western outlet of Bathurst Channel and ceasing to exist outside Breaksea Island (fig. 3). The low river input during February (figs 3 and 5) meant that the surface waters became more saline and the halocline all but

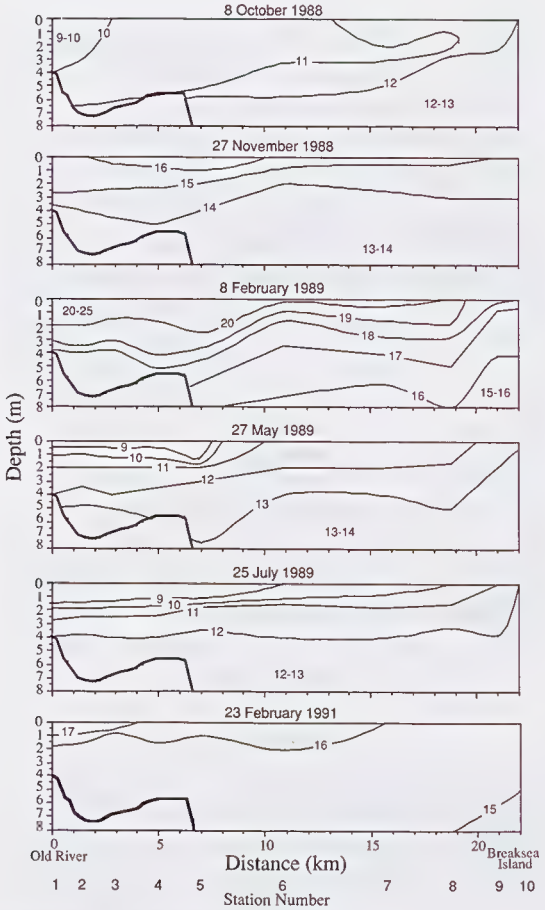

FIG. 2 — Temperature profiles (°C).

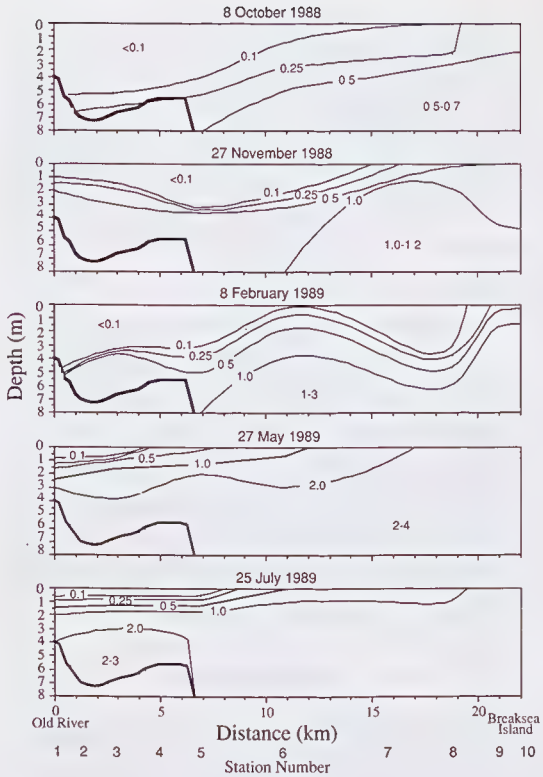

FIG. 3 — Salinity profiles (‰).

FIG. 2, 3 & 4 — Hydrological sections from the mouth of the Old River to Breaksea Island as recorded during the various field trips. Bathurst Harbour seabed is shown by bold line.

disappeared. Surface salinities in Bathurst Harbour ranged from only 7 to 15‰ over the other surveys. Freshwater input into Bathurst Harbour outside the summer months primarily acted to depress the level of the halocline and extend the distance that the brackish layer descended down the estuary, rather than dramatically reduce surface salinities. During the period of peak freshwater outflow in October 1988, the wettest month recorded at Melaleuca (D. King, meteorological records), the halocline was depressed to 6.5 m depth in Bathurst Harbour, while in other months of the year marine (>30‰) water extended to within ≈3 m of the surface. The surface waters of Port Davey between Bathurst Channel and Breaksea Island were brackish during the October survey. Fully marine (>34‰) water maintained a relatively constant depth gradient on all sampling occasions, occurring at a depth of ≈5 m at Sarah Island and gradually sinking along the channel to a depth of ≈14 m at Platypus Point.

On three surveys, the bottom salinities in the eastern and central sectors of Bathurst Harbour were higher than at corresponding depths near Platypus Point in Bathurst Channel. (At 7 m at Bathurst Harbour 1 on the November, May and July surveys, the salinities were 34.7‰, 33.0‰ and 34.0‰, while at 10 m at Platypus Point they were only 32.9‰, 31.5‰ and 33.2‰, respectively.) Bottom water in Bathurst Harbour was also markedly reduced below marine salinities (27.5‰) on the October survey. The bottom water in the harbour was clearly isolated from the marine water of the channel for much of the year, gradually diluting during these periods of isolation by the diffusion and convection of brackish water. Dense intruding marine water replenishes Bathurst Harbour bottom water whenever the halocline at the eastern end of Bathurst Channel approaches close to the surface. Such intrusions of marine water occurred on several occasions during the study period: between 9 October and 27 November 1988, during February, and between 27 May and 25 July 1989.

The bottom water in the deeper sections of Melaleuca Inlet was also isolated from Bathurst Harbour by shallow banks near Claytons Hut for much of the year. On all surveys, the bottom salinities were higher in the deep channel near the Mines Hut than downstream at Claytons Hut, while on 12 October, during peak freshwater outflow, salinities were higher at the Melaleuca Boat Landing at 3 m

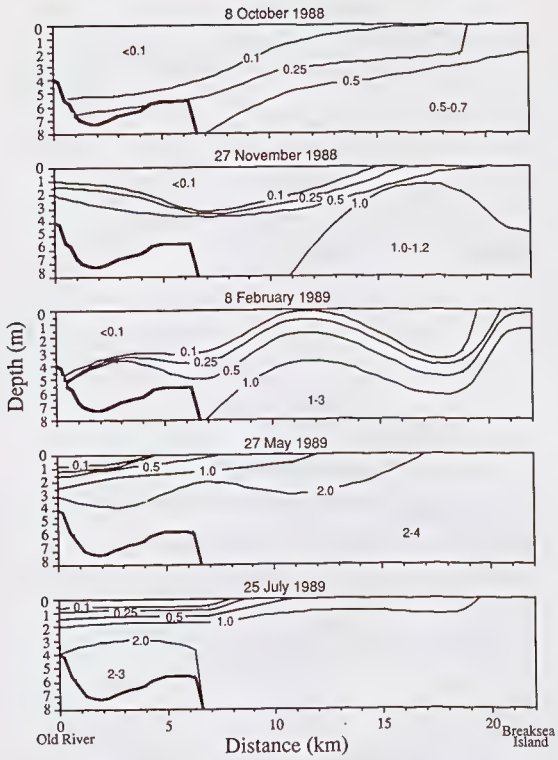

FIG. 4 — Nitrate concentration profiles (μM).

depth than at the same depth in Bathurst Harbour at Celery Top Island. During February, water throughout Melaleuca Inlet was quite saline (>25‰), with no indication of a halocline such as was observed during the other surveys.

Brackish water, and perhaps marine water in summer, enters the Old River as far as the first riffle bank (2 km upstream), but is flushed from the shallow (<1 m) sections of the river during periods of heavy rain. During summer, the only period sampled, marine bottom water was present all the way up the Davey River to the downstream end of the Davey Gorge. Surface waters were close to fresh (<5‰) down to the Davey River mouth.

Nitrate concentrations were extremely low in Bathurst Channel and Bathurst Harbour (fig. 4); nitrates were in fact undetectable (<0.1 μM) in the surface waters at the eastern end of Bathurst Harbour throughout the study. The Old River apparently provided little nitrate input into Bathurst Harbour; a surface concentration of only 0.6 μM was recorded 1 km up the Old River at the Huon Pines on 25 July 1989.

Nitrate levels increased with depth at all sites, with a maximum recorded concentration of 3.9 μM at 6 m at the Bathurst Harbour 1 station in May. Nitrate concentrations also generally increased towards Port Davey, apart from May and July 1989 when there was a slight reverse trend in waters >4 m depth.

During the cooler months, dissolved oxygen concentrations were high throughout Bathurst Harbour (table 2). At the time of the February 1989 survey, however, oxygen concentrations were extremely low at all stations sampled

TABLE 1
Temperature range (°C)* at sites in Bathurst Channel and Bathurst Harbour, 27 November 1988 to 27 July 1989

Depth (m)	Location	
	Sarah Island	Celery Top Island
1	9.0–20.2	5.1–23.1
8	11.1–18.9	9.0–19.8

* Recorded by maximum–minimum thermometers placed at 1m and 8 m depths at two sites.

(<110 μM = 46% saturation), except for surface waters near the Old River Mouth (171 μM = 74% saturation). The lowest recorded oxygen saturation level was at 20 m depth at Sarah Island (23% saturation). However, low oxygen levels were not encountered during the February 1991 survey, hence did not consistently recur in the same month on an annual basis.

Because of the extremely high tannin content of the freshwater entering the Bathurst Harbour estuary, light penetration declined rapidly up the Bathurst Harbour estuary (fig. 6), and was extremely poor outside summer. Below the halocline, however, water was highly transparent in all months. Using data collected on 23 February 1991, light transmission was found to be highly correlated with salinity ($T = 2.523 \times 10^{0.0397 \times S}$, where T is percent transmission through a 1 m column of water (i.e. $100 \times I_{n+1}/I_n$ where I is irradiance at n metre depth) and S is salinity (‰), n = 37, $R^2 = 0.85$).

Plankton

The phytoplankton community in Bathurst Harbour has a low species density, particularly during the winter and spring months when the dinoflagellate *Dinophysis acuminata* Claparede & Lachman occurs in bloom proportions. In the October and July surveys, *D. acuminata* comprised >99% of phytoplankton numbers at the Bathurst Harbour and Platypus Point sites, with the diatoms *Nitzschia* sp. and *Chaetoceros* sp. being the only other species recorded. During summer, two other dinoflagellates (*Gyrodinium* cf. *uncatenum* Hulbert and *Protoperidinium* cf. *bipes* (Paulsen) Balech) were almost as abundant as *D. acuminata*, with a number of diatoms also being present.

The number of phytoplankton species was related to the amount of marine water present. Algal species richness increased towards the western outlet of Bathurst Channel and in the months of warmer water temperatures (fig. 7). At the time of the February intrusion of marine water into Bathurst Harbour, there was little change in observed algal species richness along the estuary. This lack of an increase in species numbers towards Port Davey during summer may have been an artifact of the small sample sizes examined; a number of oceanic algae, such as the dinoflagellates *Phalacroma rotundata* Kofoid & Michener, *Ceratium massiliense* (Gourret) Jörgensen and *Ceratium furca* (Ehrenberg) Dujardin, were collected in low numbers off

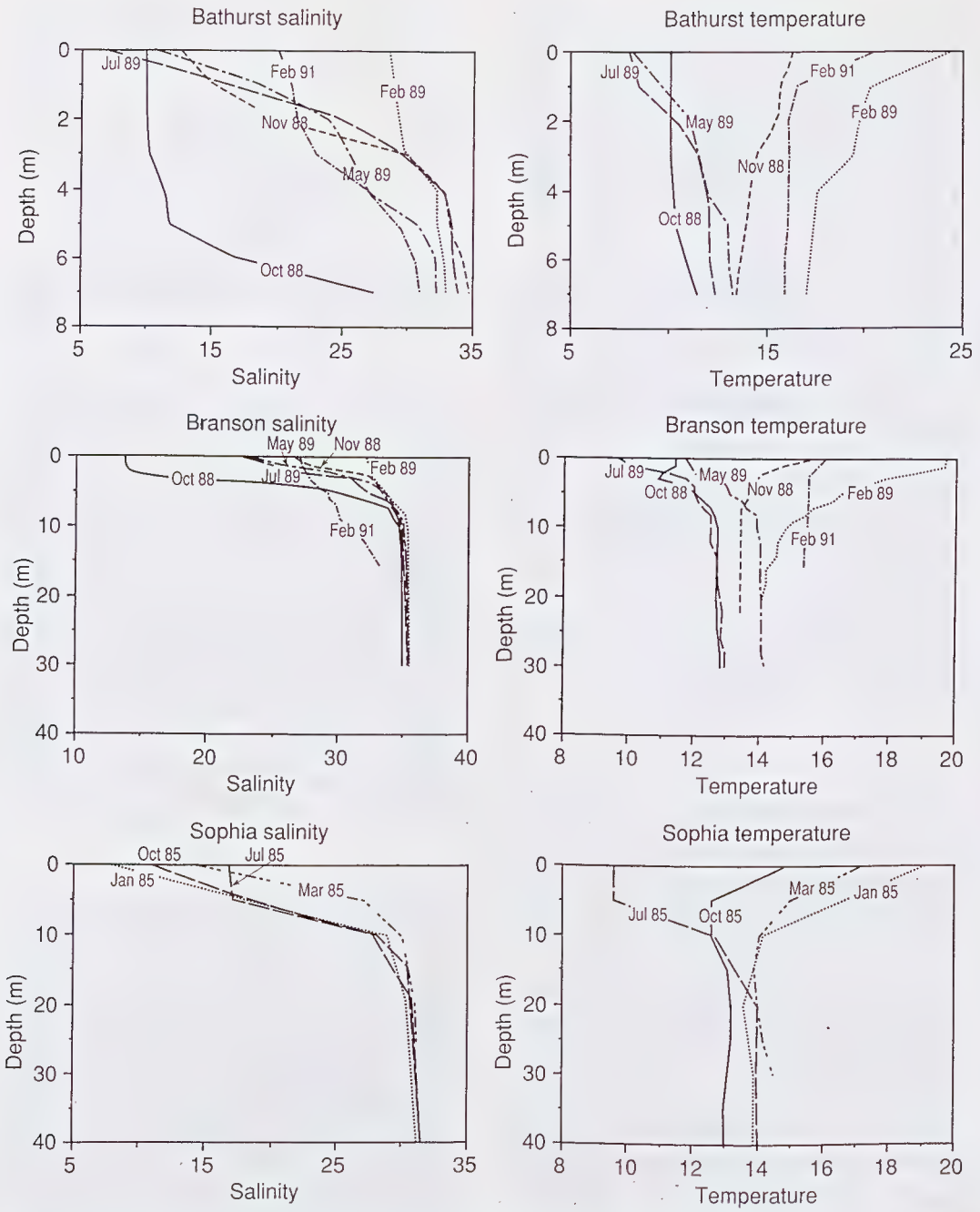

FIG. 5 — Depth profiles of temperature and salinity at sites in Bathurst Harbour (Bathurst Harbour 2) and Bathurst Channel (Branson), which are compared with a site in Macquarie Harbour (Sophia; Cresswell et al. *1989).*

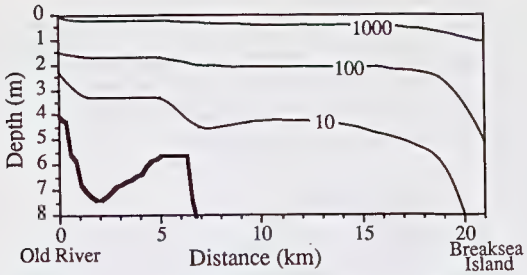

FIG. 6 — Water transparency profiles (μE.m^{-2}.s^{-1}) along the Bathurst Harbour estuary from the Old River Mouth to Breaksea Island.

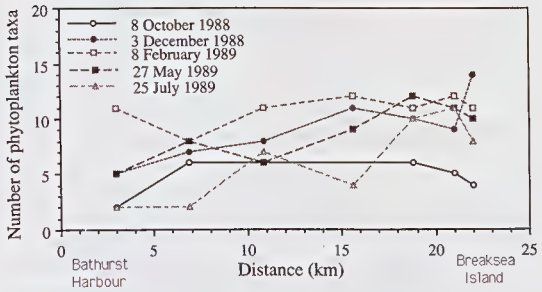

FIG. 7 — Number of phytoplankton taxa observed on microscope slides prepared from samples collected at sites in the Bathurst Harbour estuary on various dates.

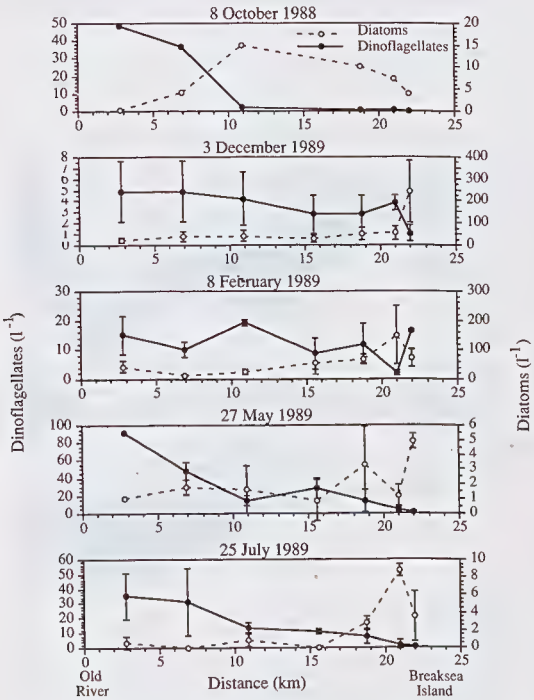

FIG. 8 — Concentration (± s.d.) of dinoflagellate and diatom cells in the Bathurst Harbour estuary on various sampling dates.

Breaksea Island but not detected upstream of Sarah Island in Bathurst Channel, even during summer.

The two major components of the sampled phytoplankton, dinoflagellates and diatoms, showed almost mirror image patterns of abundance on both spatial and temporal scales (fig 8). Dinoflagellate numbers declined in importance from Bathurst Harbour towards Port Davey while diatoms showed the opposite trend. Dinoflagellates were also most abundant during the three surveys in the cooler months, whereas diatoms were present in large numbers (>20 l^{-1}) throughout the estuary only during summer (December and February). Many of the diatoms collected were benthic forms, possibly normally living attached to sediments, marine plants or suspended humic particles.

In contrast to the hydrological data, which showed that the pattern in February was markedly different from the patterns recorded on other sampling occasions, the plankton data indicated a dichotomy between the distribution of plankton in December/February and in May/July/October. This dichotomy is apparent for phytoplankton but is more clearly seen for zooplankton (figs 9 and 10).

Zooplankton biomass (fig. 9) and abundance (fig. 10) both peaked in December and February, but their patterns of distribution did not precisely correspond, because the dominant species in October and December, the copepod *Gladioferens inermis* Nicholls, was several times larger and more than an order of magnitude heavier than the major species from February to May, the copepod *Oithona australis* Nishida. Consequently, zooplankton biomass was highest

TABLE 2

Seasonal oxygen determinations (μM) recorded in Bathurst Harbour on various sampling dates

Date	8 Oct 1988			27 Nov 1988			8 Feb 1989				27 May 1989				23 Feb 1991			
Station*	1	3	5	1	3	5	1	3	5	8	1	3	5	8	1	3	5	8
Depth (m)																		
0	285	286	275	250	251	200	171			63	266	268	258	250	243	240	224	202
2	291			243							248	253	238	252	246	243	227	202
4	286	274	260	107	236	237	106	73		72		242		252	250	240	224	202
6					233				71			234	230			230	214	202
7		236						102								218	211	205
10						232				75			232				211	205
15			258						78	68								
25										72				251				

* 1 = Old River Mouth, 3 = Bathurst Harbour, 5 = Platypus Point and 8 = Sarah Island.

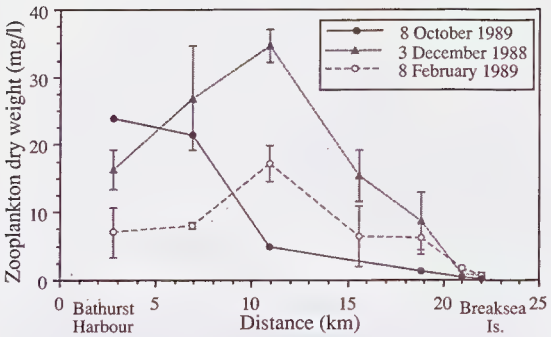

FIG. 9 — The mean biomass (± s.d.) of zooplankton at sites in the Bathurst Harbour estuary on various sampling dates. Zooplankton biomass was negligible (<1 mg/l) at all sites on 27 May 1989 and 25 July 1989 so has not been shown here.

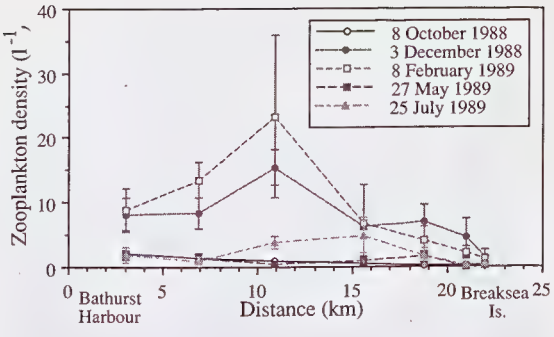

FIG. 10 — The mean abundance (± s.d.) of zooplankton at sites along the Bathurst Harbour estuary on various sampling dates.

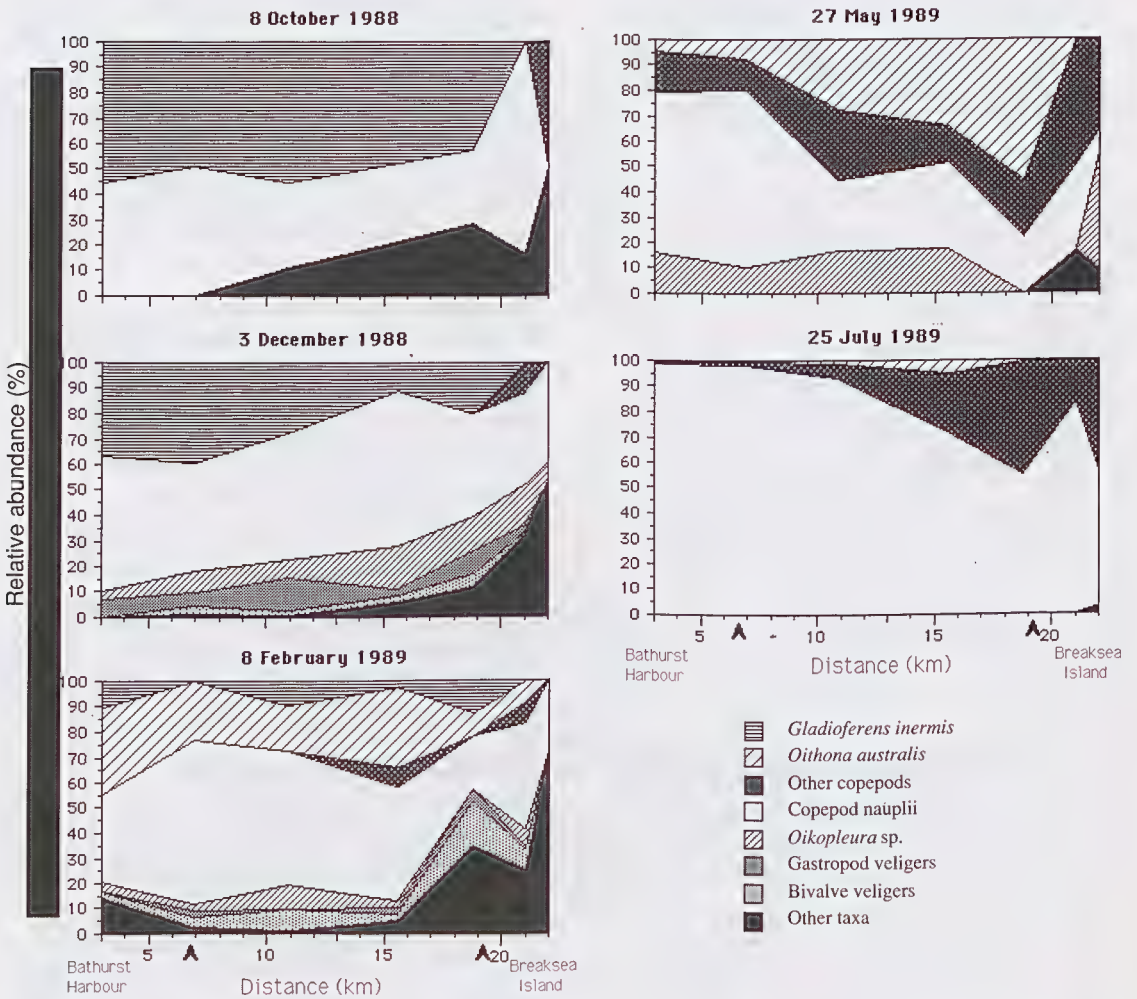

Fig. 11 — The relative abundance of major zooplanktonic taxa in samples collected at sites along the Bathurst Harbour estuary on various sampling dates.

in December while zooplankton were most abundant in February. Zooplankton biomass was also very high in Bathurst Harbour during October, a time of relatively low zooplankton abundance. The low average body size and low numbers of zooplanktonic taxa in May and July resulted in the biomass of samples from those surveys being virtually undetectable (<2 mg/l).

The distribution of zooplankton biomass along the Bathurst Channel transect did not differ markedly between the two summer surveys, except that biomass had consistently decreased from December to February by ≈50% at all sampling sites (fig. 9). The maximum biomass of zooplankton, and also maximum animal numbers, were recorded at Farrell Point in Bathurst Channel.

During the two summer surveys, the zooplankton community was much more diverse than on the other three surveys, with a large meroplanktonic component (fig. 11); large numbers of bivalve and gastropod veligers and lesser numbers of polychaete, shrimp and crab larvae and hydromedusae were recorded in summer. The dominant copepod species *Gladioferens inermis* became less important than the cyclopoid *Oithona australis* between December and February. Prior to summer, *G. inermis* was virtually the only copepod species recorded from Bathurst Harbour and the eastern end of Bathurst Channel, while from February to July a number of other taxa, most notably *Paracalanus indicus* Wolfenden and *Acartia sp.*, were present in addition to *G. inermis* and the dominant *O. australis* (fig. 11). As well as the two main copepod species, the appendicularian *Oikopleura* sp. was abundantly collected during the surveys. *Oikopleura* sp. was common throughout the Bathurst Harbour estuary between December and May, especially during summer. The category "other taxa" shown in figure 11 consisted largely of unidentified planktonic eggs and was most important towards Port Davey.

DISCUSSION

The data collected on 27 November 1988 and 25 July 1989 differed only slightly from Thomson's data (1978a,b) collected on 31 December 1977 and 20 July 1978 respectively. The two minor ways in which Thomson's surveys differed from the more recent ones in the same seasons were that more freshwater was present during the earlier surveys, and the bottom water in Bathurst Channel on 20 July 1978 was 1°C cooler than on 25 July 1989. This difference in winter water temperatures possibly reflects a slight seasonal difference in the date on which water temperatures were recorded; the temperature of 11.5°C at Hixson Point on 20 July 1978 (Thomson 1978b) is above the 11.1°C minimum temperature recorded at 8 m depth at nearby Sarah Island (table 1). A more likely explanation for the temperature difference between years is that it reflects a real interannual difference in oceanic water temperatures off southern Tasmania; Harris *et al.* (1987: fig. 8) indicated that oceanic water temperatures off Tasmania were unusually low in 1978.

Although Thomson's 31 December 1977 data were referred to by him as summer data, it is now evident that the physico-chemical environment in the Bathurst Harbour estuary changes substantially within the summer period and also between years. The hydrological regime described by Thomson (1978a) in December 1977 did not differ greatly from that reported during the cooler months, whereas the major hydrological features in February 1989 were different to those recorded in winter, most notably because
(i) marine waters penetrated with little dilution throughout the estuary, except in waters immediately adjacent to rivers and creeks;
(ii) a strong thermocline existed near the surface;
(iii) visible light penetrated below 7 m, the depth of the floor of Bathurst Harbour; and
(iv) oxygen saturation levels were low.

In this context, it should be noted that oxygen determinations in February 1989 may include some inaccuracy due to a lengthy period of time (three weeks) between the collection and laboratory analysis of samples. Samples collected on other surveys were subjected to a similar three-week time delay between collection and analysis, but they were stored at lower temperatures. It is nevertheless unlikely that oxygen concentration levels would have been grossly (>20%) inaccurate because surface samples collected on the same summer day as other samples from near the mouth of the Old River showed relatively high oxygen saturation levels. Water flowing out of the Old River was presumably near full saturation, hence surface samples collected at this station would be expected to be higher than at other sites.

Only one other estuary in Australia, Macquarie Harbour in western Tasmania, has physical and hydrological characteristics which are at all comparable with Bathurst Harbour. The Macquarie Harbour and Bathurst Harbour estuaries both have
(i) highly stratified waters, with a darkly-stained brackish surface layer, and
(ii) relatively deep (>30 m) basins, occupied by saline water, which are separated from the open sea by shallower areas.

Similarities and differences between the two systems are both apparent when the results from the present study are compared with those from seasonal surveys of Macquarie Harbour (Cresswell *et al.* 1989). To do this, we will refer to the sections in the Bathurst system (figs 2, 3 and 4) and in the Macquarie system (Cresswell *et al.* 1989: fig. 2). These are complemented by the temperature and salinity data for sites representative of Bathurst Harbour (Bathurst Harbour Station 2), the deep part of Bathurst Channel (Branson Station), and the deep part of Macquarie Harbour (Sophia Station). These are presented as depth profiles of temperature and salinity in figure 5.

Cresswell *et al.* (1989) identified three layers in Macquarie Harbour:
(i) a surface layer in the upper 10 m dominated by seasonal heating and cooling and river runoff;
(ii) a long-residence-time layer centred at 20 m, having a small annual temperature range, low oxygen content and a peak in nitrate values; and
(iii) a deep marine layer of salinity ≈31‰ in which the oxygen content increased with depth.

Figure 5 shows that the marine bottom layer in Bathurst Channel (≈35‰) is more saline than in Macquarie Harbour, which is probably a function of the respective volumes and exchanges with the ocean of the two systems. The Bathurst surveys give no indication of a mid-layer. The deep water in Bathurst Channel has somewhat paradoxical characteristics, possessing an ocean-type salinity, suggesting easy interaction with the ocean, and a relatively stable temperature, suggesting that it has its own identity.

When the Macquarie Harbour and the Bathurst Harbour and Channel temperature and salinity profiles (fig. 5) are closely compared, it can be seen that, apart from the unusual

October and February situations that are most readily apparent in the shallow Bathurst Harbour, there are many similarities at the two deep stations, such as the small temperature range at 30 m, the 10°C range of surface temperatures and the profile shapes.

The lowest levels of dissolved oxygen at Macquarie Harbour have been shown (Cresswell *et al.* 1989: figs 2 & 3)) to be ≈100 µM at ≈20 m depth, with little change between the four surveys. By comparison, dissolved oxygen was consistently ≈250 µM in the Bathurst Harbour estuary, apart from February 1989 when oxygen levels decreased to <50 µM. The low values of oxygen saturation in February may be important to the biota, probably preventing many marine animals from reaching Bathurst Harbour at that time (Edgar 1991b).

Nitrate levels were generally much lower at Bathurst Harbour than Macquarie Harbour, ranging from <0.1 to 3.9 µM at Bathurst Harbour but generally falling between 1.4 and 10 µM (i.e. 20 and 150 µg/l) at Macquarie Harbour (Cresswell *et al*. 1989). One hypothesis which explains the elevated nitrate levels at Macquarie Harbour is that there is a large nutrient input from the towns of Queenstown and Strahan; however, a more important source of nutrients is probably the freshwater entering Macquarie Harbour from the Gordon River. Most of this water has been discharged from the deeper sections of the Serpentine Impoundment, and consequently has a high nutrient load. Cresswell *et al.* (1989) indicated that the concentration of nitrate in Gordon River water entering Macquarie Harbour is ≈100 µg/l (= 7 µM), an order of magnitude higher than the level of ≈0.5 µM for water from the Old River entering Bathurst Harbour.

The surface nitrate levels at Bathurst Harbour are amongst the lowest for any estuary which has been investigated. While it is possible that the chemocline in Bathurst Harbour overturns for short periods, such as occur in Port Hacking, NSW (Rainer & Griffiths 1980), an estuary in which surface nitrate levels fall below 0.1 µM in all seasons of the year is extremely unusual; we could find no reference to another estuary worldwide with this condition. A low nutrient estuary such as this could presumably only occur when several factors combine:

(i) little nutrient input into streams within the catchment area because of inert surrounding rocks;

(ii) no anthropogenic sources of nutrients such as fertilisers, sewage or the nutrient-rich bottom waters of dams;

(iii) a highly stratified system, with no major upwelling; and

(iv) high densities of phytoplankton which rapidly absorb nutrients and ultimately cause them to be transported from surface waters to bottom sediments.

Although no current or tidal data were collected during the investigation, the salinity data allow very rough estimates of water residence times in the system to be made. The residence time of water above the halocline in Bathurst Harbour is probably relatively low (<1 mo). Most of the brackish water present in early October had been flushed from the system by late November, and all of the brackish water present at that time had disappeared by February. The maximum residence time of surface water in Bathurst Harbour is therefore considerably less than three months. It is, however, possible that the residence time of water in the top 2 m is as low as one week. Bathurst Harbour has a semidiurnal tide with an atmospheric pressure component of equivalent magnitude to the lunar component. The tidal range is generally ≈0.3 m, although most of the water moving into Bathurst Channel during each tidal cycle is probably returned during the same cycle. Because of the greater freshwater throughput during winter, surface waters should have lower residence times in winter than in summer.

The saline water near the bottom of Bathurst Harbour was isolated from marine water in Bathurst Channel on four of the five survey periods, with replenishment (i.e. an increase in salinity) occurring on several occasions during the period of the study. The salinity profile in Bathurst Harbour was generally quite stable during the ten-day periods in which field trips were carried out, hence the bottom waters were probably isolated for considerable periods of time, possibly in the order of three months.

The salinity, nutrient and light transects all change most rapidly near the western entrance of Bathurst Channel (figs 3, 4 & 6). This region corresponds to the area at which planktonic assemblages rapidly change (fig. 11), and the boundary between marine-influenced Port Davey invertebrate and fish assemblages and Bathurst Harbour estuarine assemblages (Edgar 1984, 1991a,b). The overlap zone between the marine and estuarine ecosystems can be generally defined as the small area of Bathurst Channel between Sarah Island and Hammond Point on the north shore, and Forrester Point and Turnbull Head on the south shore. This boundary is most likely a direct consequence of local water circulation patterns; west of the boundary, waters probably receive regular mixing with the marine waters of Port Davey, while east of the boundary estuarine water moves in and out with the tide but receives little mixing. This boundary also approximately corresponds with the location at which the floor of the estuary changes from sand to silt.

A primary characteristic of the Bathurst Harbour estuary is the very low diversity of planktonic taxa, with a few species thriving in extremely high densities. In addition to the data presented here, a low algal species richness is indicated by the very few dinoflagellate cyst species in the area. Sediment cores collected by Bolch & Hallegraeff (1990) from the Bathurst Harbour estuary contained only *Gonyaulax grindleyi, Scrippsiella trochoidea, Protoperidinium oblongum* and *Polykrikos schwartzii*, a low number of taxa compared with cores collected elsewhere in Tasmania, including the Derwent and Huon estuaries. Amongst 11 sites around the Tasmanian coast, only Macquarie Harbour had a similarly low number of dinoflagellate cyst taxa (Bolch & Hallegraeff 1990). This low algal species richness is probably a function of low light and nutrient levels which provide an unsuitable environment for the survival of most phytoplankton species in the estuary. The abundance and species composition of phytoplankton has been shown in numerous studies to be greatly influenced by the concentration and relative proportions of plant nutrients (Tilman 1977, Sanders *et al.* 1987, Doering *et al.* 1989). G. Hallegraeff (pers. comm.) has also suggested that trace elements may be limiting in the estuary because they probably remain strongly bound to the large quantities of humic material dissolved in the Bathurst Harbour waters.

In a recent review, Cushing (1989) summarised a number of general differences between planktonic communities in stratified and unstratified waters throughout the world. He noted that phytoplankton communities in strongly stratified waters are characterised by a predominance of dinoflagellates while diatoms are most common in weakly stratified water. Cushing (1989) postulated that, because dinoflagellates are mobile, they can position themselves near the water surface

in stratified waters during the day to exploit the high light levels. Poorly stratified waters, on the other hand, are dominated by diatoms because these algae reproduce quickly and have lower photosynthetic requirements than dinoflagellates. Surface turbulence in unstratified water was thought to cause large numbers of phytoplankton to be transported to depths with little light for growth. Cushing (1989) also noted that zooplankton biomass rapidly increases whenever thermoclines in temperate waters are overturned in spring, the time when phytoplankton communities change from being dominated by dinoflagellates to being dominated by diatoms. He interpreted these patterns in terms of the findings of Azam *et al.* (1982) that dinoflagellates were rarely a major food source for herbivorous zooplankton. In environments dominated by dinoflagellates, the major trophic pathway to zooplankton is an indirect one, through bacteria, heterotrophic flagellates and ciliates, which is largely fueled by the organic matter excreted by the dinoflagellates. Because of the number of trophic links through this microbial food loop, it supports much lower zooplankton production than the direct diatom–copepod trophic linkage.

The patterns of distribution of planktonic organisms in the Bathurst Harbour estuary generally agreed with these worldwide patterns; dinoflagellates declined in importance from the stratified waters of Bathurst Harbour to the turbulent waters of Port Davey, and also from the winter season, when a well-defined halocline was present in Bathurst Harbour, to the summer season, when a halocline was lacking.

The timing of the Bathurst Harbour phytoplankton and zooplankton successions did not agree, however, with the classical model, because zooplankton had increased to high biomass levels by October 1988. Therefore, the rapid buildup in zooplankton biomass (and presumably also production) in spring must have been fueled by dinoflagellates or unidentified smaller organisms rather than by diatoms, or else the phytoplankton community was extremely variable in time and space, and not adequately described using samples collected at bimonthly intervals.

In common with other systems, dinoflagellates were unlikely to have provided much direct food for zooplankton in Bathurst Harbour, even during the period when dinoflagellates occurred in high abundances. The major dinoflagellate species, *Dinophysis acuminata*, appeared much too large (30–50 mm long) to be ingested by zooplankton, hence a microbial food loop consisting of bacteria, small (<20 µm) phytoplankton and ciliates was probably providing most of the food for zooplankton during the dinoflagellate blooms. This hypothesis is supported by the large numbers of appendicularians present in Bathurst Harbour; this animal group is known to feed almost exclusively on organisms less than 5µm (Knoechel & Steel-Flynn 1989).

The reasons for the low densities of dinoflagellates in summer and low densities of diatoms in other periods of the year remain to be determined. Cushing's hypothesis (1989) does not explain the decline in dinoflagellate densities in summer because the estuary is quite shallow, with considerable light penetrating to the bed of the estuary in February. Moreover, the estuary was stratified on 3 December 1988, when dinoflagellate numbers were low. The abundances of dinoflagellates were, therefore, more likely to have been limited by a lack of nutrients or trace elements rather than of light during summer, possibly because diatoms were more efficient at utilising the available nutrients, due to their greater surface area/volume ratio. It should be noted, however, that nitrate concentrations were not detectably lower in summer than during spring, when dinoflagellate numbers were high. Therefore a deficiency of phosphates or trace elements rather than a lack of nitrates may have restricted dinoflagellate growth.

The concentration of diatoms was probably severely limited in Bathurst Harbour during the winter months because of the lack of accessible nitrogen in surface waters and the lack of light penetration to the deeper waters. Because dinoflagellates are motile, they would not be similarly restricted; they can move between the well-lit surface layer and the nitrate-rich waters below the chemocline (Eppley *et al.* 1968, Blasco 1978). The few phytoplankton samples collected during the study from waters below 2 m depth contained very few organisms; dinoflagellates were clearly concentrated within 1 m of the surface during the day. Other possible explanations for the low numbers of diatoms are that growth was limited by a deficiency of silica, of phosphorus or of trace elements in the estuary.

While the high abundance and biomass of copepods during summer presumably depended on diatom production, the reasons for the increase in copepod abundance prior to the October survey remain equivocal. Dinoflagellate densities were high throughout winter; it is therefore possible that picoplankton and nanoplankton were sufficiently productive during winter to sustain increased copepod production. As well as utilising exudates from dinoflagellates, planktonic bacteria may also have been directly utilising the leached organic compounds present in freshwater entering the estuary. The quantity of dissolved organic compounds entering Bathurst Harbour must be large, judging by the considerable amount of foam present along surface slicks in the area.

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REFERENCES

Azam, F., Febchel, T., Field, J.G., Gray, J.S., Meyer-Reil, L.A. & Thingstad, F., 1982: The ecological role of water-column microbes in the sea. *Mar. Ecol. Prog. Ser.* 10: 257–263.

Baker, W.E. & Ahmad, N., 1959: Re-examination of the fjord theory of Port Davey, Tasmania. *Pap. Proc. R. Soc. Tasm.* 93:113–115.

Blasco, D., 1978: Observations on the diel migration of marine dinoflagellates off the Baja California coast. *Mar. Biol.* 46: 41–47.

Bolch, C.J. & Hallegraeff, G.M., 1990: Dinoflagellate cysts in recent marine sediments from Tasmania, Australia. *Botanica Marina* 33: 173–192.

Buckney, R.T. & Tyler, P.A., 1973: Chemistry of Tasmanian Inland Waters. *Int. Revue Ges. Hydrobiol.* 58: 61–78.

Cresswell, G.R., Edwards, R.J. & Barker, B.A., 1989. Macquarie Harbour, Tasmania – Seasonal Oceanographic surveys in 1985. *Pap. Proc. R. Soc. Tasm.* 123: 63–66.

Cushing, D.H., 1989. A difference in structure between ecosystems in strongly stratified waters and those that are only weakly stratified. *J. Plankton Res.* 11: 1–13.

Doering, P.H., Oviatt, C.A., Beatty, L.L., Banzon, V.F., Rice, R., Kelly, S.P., Sullivan, B.K. & Frithsen, J.B., 1989. Structure and function in a model coastal ecosystem: silicon, the benthos and eutrophication. *Mar. Ecol. Prog. Ser.* 52: 287–299.

Edgar, G.J., 1984: Marine life and potential marine reserves in Tasmania. Part 2. *Nat. Parks Wildl. Serv. Occ. Pap.* 7: 1–102.

Edgar, G.J., 1991a: Distribution patterns of mobile epifauna associated with rope fibre habitats within the Bathurst Harbour estuary, south-western Tasmania. *Estuar. Coast. Shelf Sci.* in press.

Edgar, G.J., 1991b: Seasonal distribution patterns of fishes within the Bathurst Harbour estuary, south-western Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 37–44.

Eppley, R.W., Holm-Hansen, O. & Strickland, J.D.H., 1968: Some observations on the vertical migration of dinoflagellates. *J. Phycol.* 4: 333–340.

Harris, G., Nilsson, C., Clementson, L. & Thomas, D., 1987: The water masses of the east coast of Tasmania: seasonal and interannual variability and the influence on phytoplankton biomass and productivity. *Aust. J. Mar. Freshw. Res.* 38: 569–90.

Knoechel, R. & Steel-Flynn, D., 1989: Clearance rates of *Oikopleura* in cold coastal Newfoundland waters: a predictive model and its trophodynamic implications. *Mar. Ecol. Prog. Ser.* 53: 257–266.

Major, G.A., Dal Point, G., Klye, J. & Newell, B., 1972: Laboratory techniques in marine chemistry. A manual. *CSIRO Aust. Div. Fish Oceanogr. Rep.* 51, 60 pp.

Nyan Taw, & D.A. Ritz, 1978: Zooplankton distribution in relation to the hydrology of the Derwent River estuary. *Aust. J. Mar. Freshw. Res.* 29: 763–775.

Nyan Taw, & D.A. Ritz, 1979: Influence of subantarctic and subtropical oceanic water on the zooplankton and hydrology of waters adjacent to the Derwent River estuary, south-eastern Tasmania. *Aust. J. Mar. Freshw. Res.* 30: 179–202.

Ong, J.E., 1967: A general survey of primary productivity and the spatial and temporal distribution of the surface waters of the Derwent River estuary. Unpubl. Hons thesis, University of Tasmania.

Ong, J.E., 1969: An interesting and possibly new species of *Coreaceus* (Cyclopoida, Copepoda, Crustacea) from Port Davey. *In* McIntosh, B. (Ed.): PORT DAVEY REPORT. Unpubl. rep., Tasmania University Biological Society: 22–23.

Rainer, S.F. & Griffiths, F.B., 1980: Hydrology of an estuary with periodic deoxygenation. *CSIRO Aust., Div. Fish. Oceanogr. Rep.* 117.

Sanders, J.G., Cibik, S.J., D'Elia, C.F. & Boynton, W.R., 1987: Nutrient enrichment studies in a coastal plain estuary: changes in phytoplankton species composition. *Can. J. Fish. Aquat. Sci.* 44: 83–90.

Thomson, J., 1978a: Hydrological survey and shellfish inventory at Port Davey. SW *Tasm. Res. Surv. Disc. Pap.* 13: 1–11.

Thomson, J., 1978b: Hydrological survey, Port Davey Winter 1978. *SW Tasm. Res. Surv. Disc. Pap.* 18: 1–14.

Tilman, D., 1977. Resource competition between planktonic algae: an experimental and theoretical approach. *Ecology* 58: 338–348.

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HOLOCENE VEGETATION HISTORY FROM KING RIVER RAILWAY BRIDGE, WESTERN TASMANIA

by Guus van de Geer, Sean J. Fitzsimons and Eric A. Colhoun

(with three text-figures)

VAN DE GEER, G., FITZSIMMONS, S.J. AND COLHOUN, E.A., 1991 (20:xii): Holocene vegetation history from King River Railway Bridge, western Tasmania. *Pap. Proc. R. Soc. Tasm.* 125: 73–77. ISSN 0080–4703. Department of Geography and Environmental Studies, University of Tasmania, Box 252C GPO, Hobart, Tasmania, Australia 7001 (GvdG); Department of Geography, University of Otago, PO Box 56, Dunedin, New Zealand (SJF); and Department of Geography, University of Newcastle, Shortland, New South Wales, Australia 2308 (EAC).

Pollen analysis of a sequence of post-glacial deposits north of the old railway bridge over the King River showed that cold wet heath, with *Microstrobos* and Epacridaceae, and herbland of Gramineae, Compositae and *Astelia* occurred in the King Valley before ca. 13 000 yr BP. Temperate rainforest/wet mixed forest developed after 13 000 yr BP and was dominated by *Phyllocladus* before ca. 6400 yr BP. Between ca. 6400 and 4000 yr BP *Nothofagus* and *Eucalyptus* were co-dominant. A hiatus in deposition of organic-rich sediments occurred between 4000 and 2500 yr BP, when slope debris/alluvial fan gravels were formed. After 2500 yr BP *Phyllocladus* became dominant again. A mosaic of shrub, heath, sedge and herb communities occurred in addition to the rainforest/wet mixed forest vegetation during much of the post-glacial period. These communities seem to reflect variations in habitat and environmental conditions related to soil differences, flooding, waterlogging and burning adjacent to the King River. The pollen sequence shows the characteristic early post-glacial peak of *Phyllocladus*, the early-middle post-glacial maximum of *Pomaderris* and the middle Holocene maximum of *Nothofagus* for western Tasmania. The vegetation was influenced by burning at all times. The climate transition from cold to cool humid conditions occurred around 13 000 yr BP and was probably relatively rapid.

Key Words: Holocene, palynology, Tasmania, vegetation history

INTRODUCTION

A roadside section west of Crotty Road and 500 m north of the old railway bridge over the King River exposed a sequence of alluvial sand and gravel, organic silt, slope/alluvial fan deposits and peaty soil overlying glacial sands and gravels (fig. 1). The exposure occurred beside a Hydro Electric Commission marker post labelled K55 at grid reference 882 321 on the Franklin 1:100 000 scale Topographic Survey map. The glacial deposits were known to be outwash of Henty Glaciation age (i.e. Penultimate Glaciation) (Fitzsimons 1988). The section attracted attention because it was not known if the surface peaty soil represented the Holocene, with the slope/alluvial fan deposits and underlying silts being of last or Margaret Glaciation age, or whether they were all of Holocene age. The stratigraphy of the section was studied in the field. The silt and peat deposits were analysed for pollen, and wood samples from the base of the peat and within the silts were dated by radiocarbon to determine the age of the deposit. This paper reports the results of these investigations.

ENVIRONMENT

The site occurs at 200 m altitude adjacent to the Thureau Hills on the western side of the King Valley. It is underlain by Ordovician Crotty Quartzite which forms the footslopes of the Thureau Hills that consist mainly of Owen Conglomerate. The quartzite is mantled by Henty age outwash sands and gravels and, in places, by slope and alluvial fan deposits (Colhoun & Fitzsimons 1990).

The climate is wet and cloudy, with approximately 2500 mm precipitation distributed all year round by the maritime westerly winds. Mean temperatures at Queenstown, the nearest recording station, are 15.5°C for February and 7.1°C for July. Snow, frost and valley fogs caused by cold air drainage are common in winter.

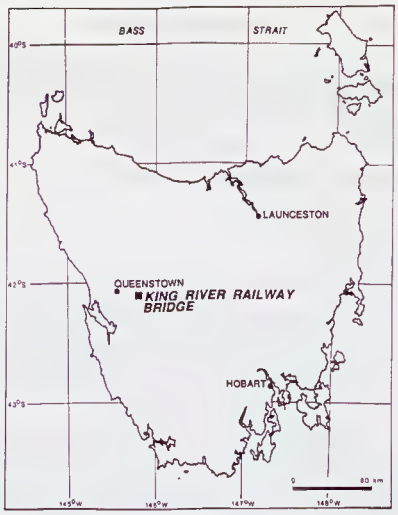
The natural vegetation of the region is potentially temperate rainforest but the vegetation has been extensively altered by the effects of firing, logging and mining (Kirkpatrick 1977). At the site, the surface vegetation consists of burnt *Melaleuca* and *Leptospermun* scrub, and of Epacridaceae (mainly *Sprengelia incarnata*) and *Gymnoschoenus sphaerocephalus* wet heath.

STRATIGRAPHY AND DATING

The stratigraphy (fig. 2) shows:
0–0.53 m — sandy blanket peat with fibrous roots and occasional wood fragments;
0.53–0.90 m — well-sorted, grey angular pebble gravel with coarse sand matrix — gravel derived from glacial deposits;
0.90–1.70 m — organic silt with wood fragments;
1.70–1.85 m — rounded pebble gravel;
1.85+ m — grey fine sand.

The stratigraphy is interpreted as Holocene blanket peat forming from local heath and bog plants on a gravel deposit of slope/alluvial fan origin. Below the gravel, silt with drifted wood fragments was deposited on a damp surface adjacent to a stream or in a shallow pond. The gravels and sand at the base are alluvial.

Two samples of wood were taken for radiocarbon dating from 0.50 m and 1.30 m depths. The results gave ages of 2520 ± 80 yr BP (SUA2597) and 7690 ± 90 yr BP (SUA2770) respectively and confirmed the age of the sequence as Holocene. This indicates that the slope/alluvial fan deposits were formed during middle to late Holocene times.



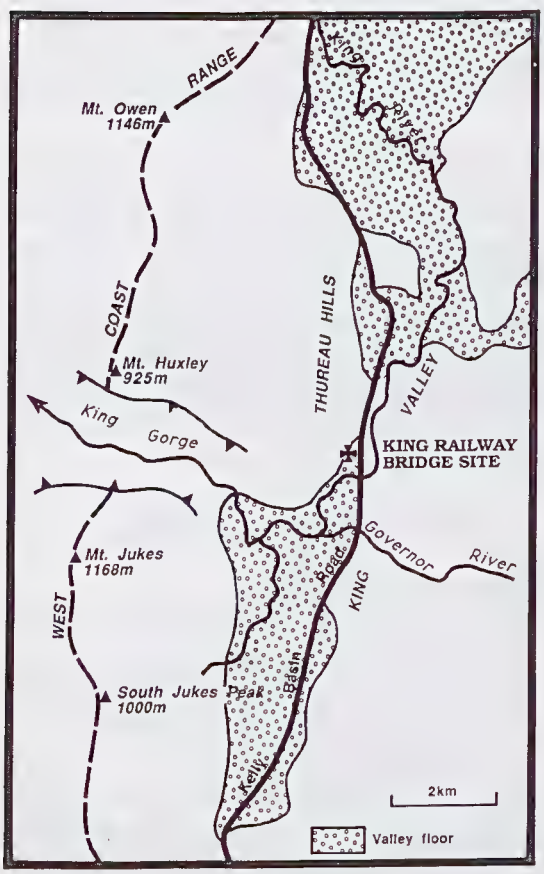


Fig. 1 — Location of King River Bridge site.

POLLEN ANALYSIS

Samples of the peat and organic silt were taken at 50 mm intervals for pollen analysis and prepared using the Faegri & Iversen (1975) method. A sum of at least 300 grains of all terrestrial taxa, excluding sedges and ferns, was used for calculating the curves of the relative pollen diagram (fig. 2). Since inclusion of all terrestrial taxa in the pollen sum emphasises the importance of local taxa at the expense of regional components of the vegetation in relative diagrams, the values were also calculated to include only the most important taxa in the regional pollen rain as indicated by Macphail (1975, 1979) for figure 3. The forms of the pollen curves for local taxa are approximately the same by both methods of calculation, so they have only been presented once in figure 2. The plant nomenclature follows Curtis (1963, 1967), Curtis & Morris (1975), Wakefield (1975) and Willis (1970). Charcoal fragments over 20 mm diameter were counted and calibrated against known quantities of introduced *Lycopodium clavatum* spores (Stockmarr 1971).

THE POLLEN DIAGRAM: DESCRIPTION AND INTERPRETATION

The relative pollen diagram can be divided into four zones KRB1 to KRB4:

ZONE KRB1, 0–0.53 m, characterised by *Phyllocladus aspleniifolius, Eucalyptus* and *Nothofagus cunninghamii* with *Lagarostrobos franklinii, Agastachys odorata, Monotoca* and *Tasmannia lanceolata.*

ZONE KRB2, 0.9–1.2 m, characterised by *Nothofagus cunninghamii, Eucalyptus* with *Bauera rubioides,* Epacridaceae, *Boronia* and *Melaleuca,* plus *Monotoca* and *Agastachys* in upper part of zone.

ZONE KRB3, 1.2–1.6 m, characterised by *Phyllocladus aspleniifolius, Nothofagus cunninghamii, Casuarina, Melaleuca* and Gramineae.

ZONE KRB4, 1.6–1.7 m, characterised by Epacridaceae, *Microstrobos niphophilus,* Gramineae, Compositae and *Astelia alpina.*

The most important pollen taxa in Zone KRB4 are Epacridaceae, *Microstrobos,* Gramineae, Compositae, *Astelia alpina* and Restionaceae. Pollen of all taxa occur in sufficiently high percentages as to indicate local presence. The vegetation was clearly dominated by small shrubs and herbs. It is unlikely that many trees were present, as *Nothofagus, Phyllocladus, Casuarina* and *Melaleuca* can all occur as shrubs.

Pollen Zone KRB3 is dominated by *Phyllocladus* with abundant Epacridaceae and *Melaleuca.* In addition, *Nothofagus, Eucalyptus* and *Leptospermum* occur in substantial quantities throughout the zone. *Casuarina* and *Pomaderris* have distinct maxima in the lower part of the zone while *Bauera* expands in the upper part. Gramineae and Compositae decline throughout the zone. Restionaceae and Cyperaceae attain peaks early in the zone and decrease upwards. Pollen of alpine and subalpine taxa are so low that presence of the plants on site is unlikely. The vegetation would appear to have consisted of mainly trees and shrubs with a subsidiary herb component.

Pollen Zone KRB2 is dominated by *Nothofagus* with large quantities of *Eucalyptus* and *Phyllocladus.* Epacridaceae and *Melaleuca* form large components of the pollen assemblage that also includes notably *Agastachys, Bauera,*

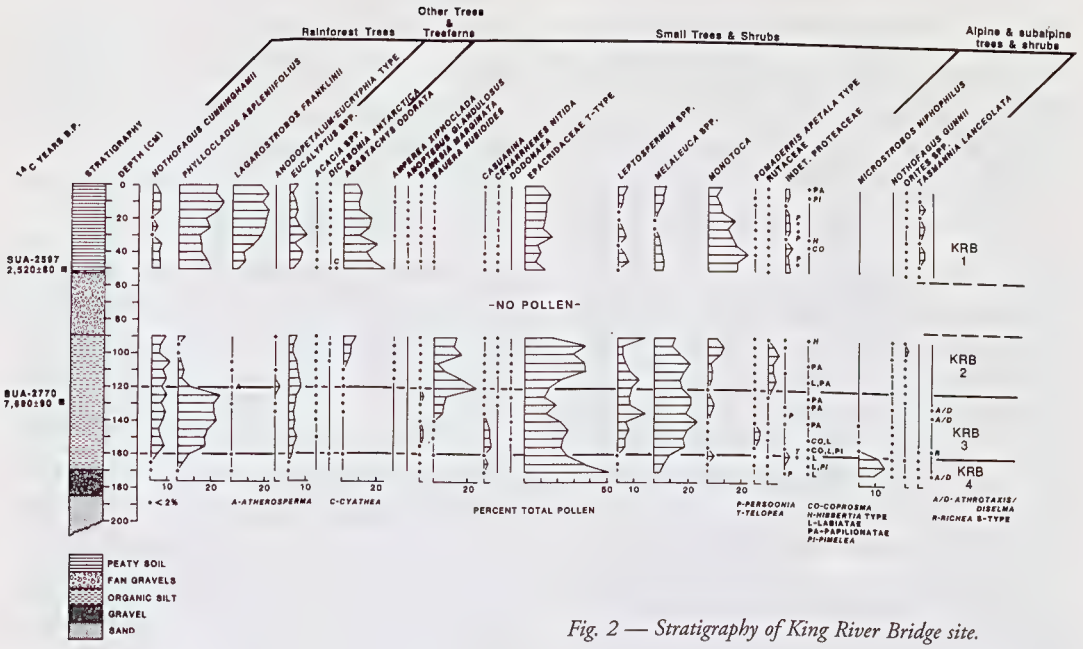


Fig. 2 — Stratigraphy of King River Bridge site.

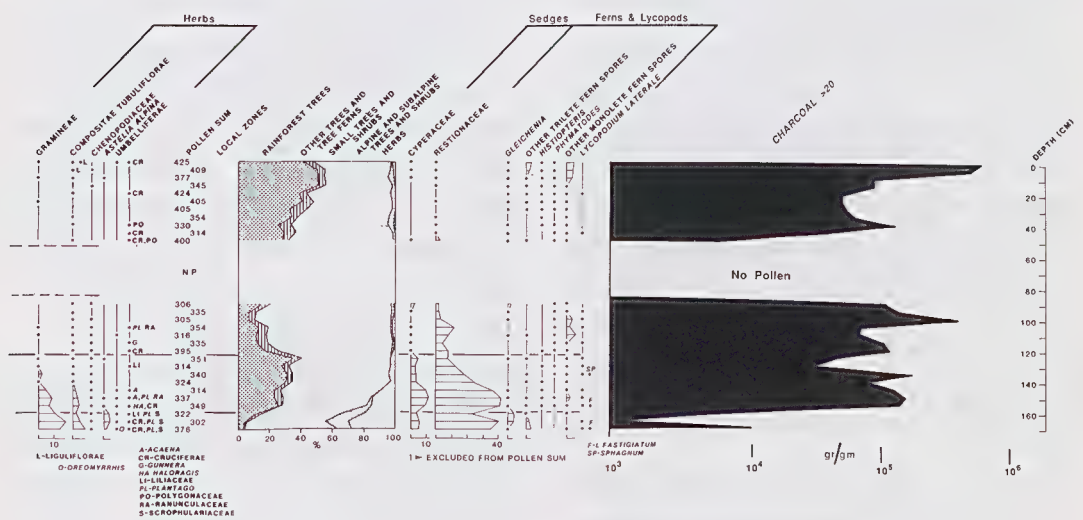


Fig. 3 — Relative pollen diagram.

Leptospermum, Monotoca and Rutaceae (cf. *Phebalium squameum* and *Boronia*). Except for Restionaceae few sedges, herbs or alpine and subalpine taxa are represented. The vegetation apparently consisted predominantly of mature forest trees, and of understorey tree and shrub taxa.

Pollen Zone KRB1 differs from Zone KRB2 by the re-expansion of *Phyllocladus* to dominance and reduction in *Nothofagus* while *Eucalyptus* maintains similar quantities. *Lagarostrobos, Agastachys* and *Monotoca* have high pollen values which indicate considerable local presence of these tree and shrub taxa. The sclerophyll shrub taxa Epacridaceae, *Leptospermum* and *Melaleuca* are much lower than in KRB2. Proteaceae and *Tasmannia* are present in moderate amounts for the first time. The vegetation appears to have been composed of forest tree taxa and a relatively diverse shrub flora.

The vegetation of Zone KRB4 is interpreted as representing the development of alpine heath and herbland on the floor of the King Valley in late glacial times. The heathland was characterised by the presence of considerable

quantities of the endemic alpine conifer *Microstrobos* amongst, presumably, a variety of epacrids, while the herbland was dominated by grasses and composites. The presence of the alpine/subalpine *Astelia* also indicates cold wet habitat conditions. *Casuarina*, probably the shrub *C. monilifera*, was present in the heath but no other trees were necessarily present. Restionaceae was probably present in the heath and adjacent to the river bank or lake margin.

The inferred vegetation of this pollen assemblage zone is similar to that recorded at other sites in western Tasmania immediately succeeding the period of deglaciation (Macphail 1979, Colhoun *et al.* 1991a). The sediment probably commenced accumulating in the late glacial (i.e. 14–10 ka BP) but the age of the upper boundary is not known. However, at Governor Bog, 2 km south of the King River Railway Bridge site, where an attenuated late glacial sequence was recorded, the end of the alpine conifer *Microstrobos* phase was dated at 13 020 ± 130 yr BP (SUA 2723). The proximity of the sites and the abrupt termination of *Microstrobos*, along with changes in associated taxa in both diagrams, suggest that the event was synchronous (Colhoun *et al.* 1991a). Thus, it appears that the KRB4/3 zone boundary is approximately 13 000 years old and reflects an alteration from cold alpine to temperate vegetation and climatic conditions.

The vegetation of Zone KRB3 represents the phase of early Holocene rainforest/wet mixed forest expansion. The *Phyllocladus* "bulge" is very well represented and is a noted feature of early post-glacial pollen diagrams from western Tasmania (Macphail 1983); it is usually accompanied by a *Pomaderris* peak indicating the development of understorey taxa in the wet forests. The peak of *Casuarina* in the lower part of the zone, together with large quantities of Epacridaceae, *Melaleuca* and Restionaceae, indicate that rainforest/wet mixed forest with *Eucalyptus* had not yet fully developed during deposition of the lower part of the zone but the decrease in Epacridaceae and Restionaceae up through the zone suggests that forest vegetation was expanding. To what extent the *Melaleuca*, Epacridaceae and Restionaceae values reflect the co-occurrence of scrub, heath and sedge communities as a mosaic within the developing wet forests is difficult to judge but, given the location of the site adjacent to a major river, where forest development could be limited locally by flooding, waterlogging or the effects of fire, such complexity of structure is likely. The composition and inferred structure of the vegetation indicates that the climate must have been cool and humid throughout KRB3 time.

The age of Zone KRB3 has not been precisely determined, as only one wood sample was dated at 130 cm to 7690 ± 90 yr BP (SUA 2770). If the lower boundary estimate of 13 000 yr BP is correct and if reasonably continuous sedimentation occurred at the site, then the upper boundary would have an age of about 6400 yr BP. While unlikely to be precise, such an estimate is consistent with the known range of the *Phyllocladus* "bulge" in western Tasmania, which generally precedes 7000 yr BP (Macphail 1979, Colhoun *et al.* 1991a, Colhoun, pers. comm.).

During Pollen Zone KRB2, *Nothofagus* and *Eucalyptus* both became more important than *Phyllocladus* in the regional pollen flora and presumably also local vegetaion (fig. 3). The data suggest the development of a wet mixed forest with a diverse understorey that includes notably *Pomaderris*, *Bauera*, *Monotoca*, Rutaceae (mainly *Phebalium squameum*) and *Agastachys*. However, these taxa are accompanied by relatively high values for Rutaceae (cf. *Boronia*) and *Orites*, and very high values for Epacridaceae, *Melaleuca* and *Leptospermum* which show that scrub and heath taxa were important components of the local vegetation. In addition, moderate quantities of Cyperaceae and Restionaceae indicate the common occurrence of sedges. The pollen assemblage of Zone KRB2, therefore, suggests that the vegetation near the site probably consisted also of scrub, heath and sedge communities, perhaps in a strongly mosaiced pattern related to the local topography and poor drainage conditions adjacent to the King River.

The age of Zone KRB2 is certainly younger than 7690 ± 90 yr BP (SUA 2770) and probably younger than 6400 yr BP. The zone was truncated before 2520 ± 80 yr BP (SUA 2597). Extrapolation from 7690 ± 90 yr BP, on the basis of uniform sedimentation rate for the silt, would suggest an age of about 4000 yr BP for the truncation of zone KRB2. It is recognised that the assumption of uniformity in sedimentation rate is not likely to represent reality for sites adjacent to a large river in which ephemeral sedimentation influxes are more likely than gradual accumulation. The *Nothofagus* maximum and high values of *Pomaderris apetala* are known to characterise early-middle Holocene pollen sequences from western Tasmania (Macphail 1979, 1983). The *Nothofagus* maximum is usually attained by ca. 7000 yr BP but appears to be slightly later here. However, the values of *P. apetala* recorded in Zone KRB2 and occurence of the *Nothofagus* maximum are consistent with a middle Holocene age for the sediments.

It is difficult to judge the duration of the period when the slope deposits/fan gravels accumulated. Some of the pollen curves show marked discontinuity in values, e.g. *Phyllocladus*, *Bauera*, Epacridaceae and *Melaleuca*, while others show remarkable continuity, e.g. *Eucalyptus*, *Monotoca* and *Agastachys*. Some temporal hiatus must be implied by sharp discontinuity, while continuous curves do not necessarily demonstrate temporal continuity. However, the estimated age of the top of the silt at ca. 4000 yr BP and the dated base of the peaty soil at 2520 ± 80 yr BP (SUA 2597) suggests an interval of perhaps ≈ 1500 years.

During the last 2500 years represented by KRB1, *Phyllocladus* was the dominant wet forest taxon with *Eucalyptus* and *Nothofagus*. Together these taxa indicate the occurrence of wet mixed forest, while the relative abundance of *Lagarostrobos franklinii*, *Agastachys* and *Monotoca* suggests strong presence of riparian forest and wet scrub vegetation. It is notable that this site is very close to the upstream limit of *Lagarostrobos* in the King Valley today, whereas at Smelter Creek, less than 1 km to the south, *Lagarostrobos* expanded at around 5000 yr BP, and at Governor Bog, 2 km to the south, around 11 000 yr BP (Colhoun *et al.* 1991a,b). The increased Proteaceae and *Tasmannia* indicate a greater diversity of shrubs which could have resulted from several factors including increased burning, flooding, change of substrate from silt to peaty soil or possibly even reduction in temperature. However, the data are insufficient to determine the cause of the change noted in the pollen assemblage.

The counts of charcoal particles over 20 μ m size indicated that fire was present throughout the period. The highest values of 510 to 622 × 10^3 grains/gram occur in the top 5 cm and indicate the recent high intensity/frequency of burning. Throughout the rest of the profile, values generally vary from 0.9 to 178 × 10^3 grains/gram except at 100 cm where 401 × 10^3 grains/gram were recorded. The mean

value is 125.7 and standard deviation 144.5. The very high surface values coincide with the period of European exploitation of the valley. The lowest values, 0.9 to 9.8 × 10^3 grains/gram, occur below 160 cm and coincide with the alpine herbfield and *Microstrobos* heath vegetation. Throughout the rest of the profile, there is no correlation between charcoal concentration and the wet forest vegetation, which developed and was modified despite repeated firing.

CONCLUSION

The short sequence of pollen-bearing sediment from King River Bridge appears to extend from late glacial to modern time, with a short interruption occasioned by the deposition of slope (landslide?) and alluvial fan gravels. Comparison with Governor Bog suggests that the alpine heathland and herbland of Zone KRB4 was developed before 13 000 yr BP and that the climate was cold and wet. After 13 000 yr BP the rainforest taxa *Phyllocladus* and *Nothofagus* expanded in Zone KRB3 and the vegetation was a mosaic of rainforest/wet mixed forest, scrub, heath and sedge communities adjacent to the King River until about 6400 yr BP. After 6400 yr BP, *Phyllocladus* declined and the wet mixed forest understorey was co-dominated by *Nothofagus* and *Eucalyptus* in Zone KRB2. The forest understorey appears to have become more diverse, and scrub, heath and sedge communities also occurred in what was probably a mosaic of vegetation communities close to the flood-prone margins of the King River. During the last 2500 years the wet mixed forest was again dominated by *Phyllocladus* while *Lagarostrobos* expanded to its uppermost point along the course of the King River. The co-occurrence of *Agastachys*, Proteaceae and *Tasmannia* suggests that wet scrub vegetation was more important than sclerophyll heath and scrub. After 13 000 yr BP the climate appears to have been always cool and wet, and favourable for the development of temperate rainforest. The complexity of the pollen assemblages suggests the maintenance of a mosaic of vegetation communities adjusted to the effects of sediment variation, flooding and waterlogging adjacent to the King River and to burning throughout the Holocene.

ACKNOWLEDGEMENTS

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REFERENCES

Colhoun, E.A. & Fitzsimons, S.J., 1990: Late Cainozoic glaciation in western Tasmania, Australia. *Quat. Sci. Rev.* 9: 199–216.

Colhoun, E.A., van de Geer, G. & Fitzsimons, S.J., 1991a: Late glacial and Holocene vegetation history at Governor Bog, King Valley, western Tasmania. *J. Quat. Sci.* 6(1): 55–66.

Colhoun, E.A., van de Geer, G. & Fitzsimons, S.J., 1991b: Late Quaternary organic deposits at Smelter Creek and vegetation history of the middle King Valley, western Tasmania. *J. Biogeogr.* 18: 1–11.

Curtis, W.M., 1963, 1967: *THE STUDENT'S FLORA OF TASMANIA, PARTS 2 AND 3.* Government Printer, Hobart.

Curtis, W.M. & Morris, D.I., 1975: *THE STUDENT'S FLORA OF TASMANIA, 2ND EDN, PART 1.* Government Printer, Hobart.

Faegri, K. & Iversen, J., 1975: *TEXTBOOK OF POLLEN ANALYSIS.* 3rd Edn, Munksgaard, Copenhagen.

Fitzsimons, S.J., 1988: The Quaternary Stratigraphy of the King Valley. Unpubl.PhD Thesis, University of Tasmania.

Kirkpatrick, J.B., 1977: The impact of man on the vegetation of the West Coast Region. *In* Banks, M.R. & Kirkpatrick, J.B. (Eds): *LANDSCAPE AND MAN.* Royal Society of Tasmania, Hobart: 151-156.

Macphail, M.K., 1975: Late Pleistocene environments in Tasmania. *Search* 6(7): 295–300.

Macphail, M.K., 1979: Vegetation and climates in southern Tasmania since the last glaciation. *Quat. Res.* 11: 306–341.

Macphail, M.K. 1983: The early to middle Holocene *Pomaderris* maximum in southeastern Australia. *In* Chappell, J.M.A. & Grindrod, A. (Eds): *PROCEEEDINGS OF THE FIRST CLIMANZ CONFERENCE.* Howman's Gap, 1981. Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, Canberra: 105–106.

Stockmarr, J., 1971: Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13: 615–621.

Wakefield, N.A., 1975: *FERNS OF VICTORIA AND TASMANIA.* Field Naturalists Club of Victoria, Griffin Press, Adelaide: 80 pp.

Willis, J.H., 1970: *A HANDBOOK OF PLANTS OF VICTORIA. VOL. 1 (FERNS, CONIFERS AND MONOCOTYLEDONS).* 2nd Edn, Melbourne University Press: 481 pp.

(accepted 9 August 1991)

ERRATA

MID-MESOZOIC LEAVES FROM NEAR IDA BAY, SOUTHERN TASMANIA, AUSTRALIA

by W.D. Tidwell, J. Kim and T. Kimura

Pap. Proc. R. Soc. Tasm. 121: 159–170.

Page 161, fig. 2, line 3: showing venation (i, vi, v) should read: showing venation (i, iv, v).
Page 163, under Bennetiales and *Otozamites* sp.: Pl. II, figs 2, 3 should read: Pl. I, fig. 6; Pl. II, fig. 3.
Page 168, plate I, fig. 3: Specimen number should read Z2303, not Z2302.
Page 168, plate I, fig. 5: Specimen number should read Z2303, not Z23030.

OGURACAULIS BANKSII GEN. ET SP. NOV., A MID-MESOZOIC TREE-FERN STEM FROM TASMANIA, AUSTRALIA

by W.D. Tidwell, H. Nishida and N. Webster

Pap. Proc. R. Soc. Tasm. 123: 15–24.

Page 20, plate 3, fig. B: Specimen umber should read: Z2290 not Z2240.
Page 24, left column, line 10: instead of *Oguracaulis banksii*, should read *Cibotium tasmanense.*

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 125

Contents

	page
Annual report	iv
HANNAN, D.G. & COLHOUN, E.A. — When were the Walls of Jerusalem last glaciated?	1
RUHBERG, H., MESIBOV, R., BRISCOE, D.A. & TAIT , N.N.— *Tasmanipatus barretti* gen. nov., sp. nov. and *T. anophthalmus* sp. nov.: two new and unusual onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania	7
MESIBOV, R. & RUHBERG, H. — Ecology and conservation of *Tasmanipatus barretti* and *T. anophthalmus*, parapatric onychophorans (Onychophora:Peripatopsidae) from northeastern Tasmania.	11
SHAPCOTT, A. — Dispersal and establishment of Huon pine (*Lagarostrobos franklinii*)	17
TAYLOR, R.J. — Distribution and habitat of *Helicarion rubicundus* (Pulmonata: Helicarionidae), a rare land snail.	27
HORWITZ, P. & KNOTT, B. — The faunal assemblage in freshwater crayfish burrows in sedgeland and forest at Lightning Plains, western Tasmania	29
PEMBERTON, D., BROTHERS, N. & COPSON, G. — Predators on marine fish farms in Tasmania	33
EDGAR, G.J. — Seasonal distribution patterns of fishes within the Bathurst Harbour estuary, southwestern Tasmania	37
PLOMLEY, B. & BARBER, L. — The form of the hair follicle in the human scalp as an indicator of human relationships	45
ANDREWS, A.P. — Observations on the Tasmanian mudfish, *Galaxias cleaveri* (Pisces: Galaxiidae)	55
EDGAR, G.J. & CRESSWELL, G.R. — Seasonal changes in hydrology and the distribution of plankton in the Bathurst Harbour estuary, southwestern Tasmania, 1988–89	61
VAN DE GEER, G., FITZSIMONS, S.J. & COLHOUN, E.A. — Holocene vegetation history from King River Railway Bridge, western Tasmania	73
ERRATA:	
TIDWELL, W.D., KIM, J. & KIMURA, T. — Mid-Mesozoic leaves from near Ida Bay, southern Tasmania, Australia	79
TIDWELL, W.D., NISHIDA, H. & WEBSTER, N. — *Oguracaulis banksii* gen. et sp. nov., a mid-Mesozoic tree-fern stem from Tasmania, Australia	79

Design of front cover and spine by Mr Chris Cowles, Tasmanian School of Art, University of Tasmania.

P 506
R 888
TP